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AND

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Issue of Journal. The Journal appears in four parts per sessional volume, viz. in January, April, July and October. A brochure describing the origin, progress and purposes of the Institution, and comprising also the Memorandum and Articles of Association, the By-Laws and Regulations of the Institution, the Library Catalogue to date (with subject index), and the List of Members, was published in September, 1915, to be followed periodically by revisions of the Library Catalogue and List of Members.

Members of all classes are entitled to receive these publications free: for additional copies of the Journal they will be charged at the price of seven shillings and sixpence per part, and of the brochures at the prices stated on the wrappers, varying in proportion to bulk.

Changes of Address. It is particularly requested that members notify the Secretary immediately of any change of address; and members are also requested to advise the Parcel Post Department as well as the Letter Office, of any temporary change of address, as, unless this is done, parcel post packets will not be re-addressed; but will be returned to the offices of the Institution in London, thus incurring further expense for postage.

To Authors of Papers. Papers should be written in the third person, and the copy should be carefully corrected by the author before it is presented.

All drawings, diagrams or other illustrations should be sent in a fit state for direct photographic reproduction.

All quotations, technical terms, and localisms should be indicated by means of inverted commas.

Foreign weights, measures, and costs should be given whenever possible, and also their English equivalents.

It is suggested that authors append as complete a bibliography of the subject treated as may be possible.

All papers and notes submitted to the Institution are supposed to be original communications unless distinctly stated to be otherwise, in which case the exact reference to the previous publication should be given.

Communications upon papers read at meetings, notices of personal movements, or other matter for which publication is desired in the next issue of the Journal, should be in the hands of the Editor on or before the last day of December, March, June or September as the case may be. Subsequent delivery may be too late for insertion.

The Council desire to draw the attention of authors to the serious increase in the cost of production. Papers, both for the Journal and for communication to the Institution, should be as concise and condensed as possible.

Communications. The Council invite members to submit papers for the forthcoming session. Communications to the Institution will, subject to the approval of the Publication Committee, be published in the Journal.

Appointments Register. A Register will be kept at the Offices of the Institution for the convenience of firms requiring the services of members and for members requiring appointments, but on the distinct understanding that the Institution accepts no responsibility and gives no guarantee.

Library. The Institution's Library is in course of reorganisation in the new premises at No. 5 John Street, Adelphi, and may be consulted between 11 and 4 daily. Extensive additions are being made to the current and standard literature on Petroleum.

Since the issue of the last "Journal" the following Books and Publications have been received :—

From Mons. Paul de Chambrier :—

Exploitation du Pétrole par Puits et Galleries. By M. Paul de Chambrier.

Le Bassin Pétrolifère de Péchelbronn (Alsace). By M. Gignoux and C. Hoffmann.

From H.M. Petroleum Department of the Government :—

Typewritten Report of Drilling Operations in the U.K. for year ending December 31st, 1920.

From Government Publications Office, Cairo, through the courtesy of Dr. W. F. Hume, Director Geological Survey, Egypt :—

1. Programme and Policy of the Government with regard to Petroleum. 2. Petroleum Bulletins : Nos. 2, 3, 4, 7, and 8. Bulletins Nos. 1 and 6 have not yet been issued, but will be forwarded in due course.

From Department of Scientific and Industrial Research Advisory Council :—

Report of the Lubricants and Lubrication Inquiry Committee.

From U.S. Geological Survey :—

Mineral Resources of the United States, Part 1, 1914 ; Part 1 and 2, 1914 and 1915 ; Part 1 and 2, 1916 ; Part 2, 1917.

From Mines Branch (Canada) :—

Summary Report of the Mines Branch of the Department of Mines for 1918 and 1919. Report on the Mineral Production of Canada for 1916 and 1917.

From the Canadian Government Trade Commissioner :—

New Oil Fields of Northern Canada. By F. H. Kitto.

From the Author :—

Coal in Great Britain. By Walcot Gibson, D.Sc., F.G.S.

From Mr. E. Lawson Lomax the following U.S. Bulletins :—

Technical Paper 26, 1912. Methods of Determining the Sulphur Content of Fuels, especially Petroleum Products. By Irving C. Allen and I. W. Robertson.

Technical Paper 38, 1913. Wastes in the Production and Utilization of Natural Gas and Means for their Prevention. By Ralph Arnold and Frederick G. Clapp.

Technical Paper 74, 1914. Physical and Chemical Properties of the Petroleums of California. By Irving C. Allen, Walter A. Jacobs, A. S. Crossfield and R. R. Mathews.

Technical Paper 109, 1915. Composition of the Natural Gas Used in Twenty-Five Cities, with a discussion of the Properties of Natural Gas. By G. A. Burrell and G. G. Oberfell.

Technical Paper 115, 1915. Inflammability of Mixtures of Gasoline Vapor and Air. By G. A. Burrell and H. T. Boyd.

Technical Paper 117, 1916. Quantity of Gasoline Necessary to Produce Explosive Conditions in Sewers. By G. A. Burrell and H. T. Boyd.

Technical Paper 120, 1915. A Bibliography of the Chemistry of Gas Manufacture. By W. F. Rittman and M. C. Whitaker.

Technical Paper 131, 1916. The Compressibility of Natural Gas at High Pressures. By G. A. Burrell and I. W. Robertson.

Technical Paper 158, 1917. Compressibility of Natural Gas and its Constituents with Analyses of Natural Gas from thirty-one cities in the United States. By G. A. Burrell and I. W. Robertson.

Technical Paper 163, 1916. Physical and Chemical Properties of Gasolines sold throughout the United States during the Calendar year 1915. By W. F. Rittman, W. A. Jacobs and E. W. Dean.

Technical Paper 166, 1917. Motor Gasoline Properties, Laboratory Methods of Testing, and Practical Specifications. By E. W. Dean.

Technical Paper 181, 1917. Determination of Unsaturated Hydrocarbons in Gasoline. By E. W. Dean and H. H. Hill.

Bulletin 125, 1916. The Analytical Distillation of Petroleum. By W. F. Rittman and E. W. Dean.

Bulletin 151, 1918. Recovery of Gasoline from Natural Gas by Compression and Refrigeration. By W. P. Dykema.

Bureau of Standards. Department of Commerce :—

No. 4, 1911. The effect of added Fatty and other Oils upon the Carbonization of Mineral Lubricating Oils. By C. E. Waters.

No. 16, 1916. The Testing of Hydrometers.

No. 57, 1916. United States Standard Tables for Petroleum Oils.

No. 77, 1916. Density and Thermal Expansions of American Petroleum Oils. By H. W. Bearce and E. L. Peffer.

No. 112, 1918. Standardization of the Saybolt Universal Viscosimeter. By Winslow H. Herschel.

No. 160, 1911. The Behaviour of High-Boiling Mineral Oils on Heating in the Air. By C. E. Waters.

No. 298, 1917. Standard Substances for the Calibration of Viscometers. By Eugene C. Bingham and Richard F. Jackson.

From the Union Petroleum Company, Philadelphia :—

The Petroleum Problem. (Some fundamentals of the Petroleum Problem. Petroleum Problems of the United States. The Petroleum Problem of the World.). By M. L. Requa.

The following Books have been purchased :—

Lubricating and Allied Oils. By Elliott A. Evans.

1916 Edition of Engler-Höfer, Das Erdöl.

The attention of members is drawn to the new supplement of the Journal which deals with current Petroleum literature. To make this section of the maximum usefulness it is necessary that there should be full co-operation between chemists, engineers and geologists, and that matter which has inadvertently escaped notice shall be immediately sent in to the Editor. The Institution has been indebted to Mr. Andrew Campbell for the compilation of the bibliography during this past session, and is now under similar obligation to Mr. W. J. Wilson.

Advertisements in the Journal. A limited number of Advertisements of firms interested in the Petroleum Industry may be inserted in the Journal. Application for terms, etc., should be made to the Secretary.

LIST OF ADVERTISERS.

(Members are desired, when making enquiries or placing orders with advertisers, to mention that they have seen their announcement in the Journal.)

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PERSONAL NOTES OF MEMBERS AND SPECIAL NOTICES.

It is suggested that Members of the Institution send information regarding their movements to the Secretary for insertion under this heading.

Mr. WILLIAM CALDER has left for Trinidad, W.I.

Mr. F. M. PENNEY has returned from the Republic of Colombia.

Professor TOYOKICHI TAKAKUWA has returned to Japan via New York.

We have to regret the untimely death of Mr. C. P. HAMMOND,

Member, who died on March 13th. He was associated until his death with the firm, Messrs. Hayward-Tyler & Co., Ltd., 99, Queen Victoria Street, London, E.C.4.

We have received the first number of the Bulletin of the American Society for Testing Materials. Of interest to Petroleum chemists is an article on the development of tests for Petroleum products and new methods are foreshadowed.

To increase the usefulness of the Journal a column of Petroleum Notes will be opened. Members are requested to forward to the Editor items of general interest. Correspondence relating to the business of the Institute or to Petroleum matters will be inserted in future issues. Contributors to the discussions are urged to send their communications in duplicate to the Secretary.

We have received from Messrs. H. K. Lewis and Co., Gower Street, a copy of their important and indispensable catalogue of recently published scientific books.

The SPECIAL MEETING of the Institution, to exhibit the film entitled "The Story of Petroleum," prepared by the United States Bureau of Mines in collaboration with the Sinclair Consolidated Oil Corporation, held at the Hall of the Institution of Mechanical Engineers, Storey's Gate, St. James' Park, S.W. 1, on Monday, March 21st, 1921, was attended by more than 400 members and visitors.

REVIEWS.

"Liquid Fuels for Internal Combustion Engines." By H. MOORE, M.Sc.Tech., A.I.C., F.C.S., A.M.Inst.P.T. Second Edition, 1920. Pp. 206. (*Crosby, Lockwood & Son.*)

When Mr. Moore's book on Liquid Fuels for Internal Combustion Engines appeared in 1918 it was welcomed by chemists and engineers not only as the first work devoted entirely to this comparatively recent development of power production, but more particularly as a work which bore throughout indubitable testimony to the high qualifications of the writer to speak with authority on the theoretical and the practical aspects of the subject.

The second edition now published differs but little from the first. Recent researches of the author on spontaneous ignition temperatures and on an improved tar oil injector have been incorporated, and the large selection of official specifications and of analyses of commercial fuels which were such a valuable feature of the first edition have been revised and extended.

The book comprises three sections. The first gives a brief account of the chief fuels (petroleum, shale oil, coal lignite and wood tars, fatty oils and alcohols).

The second deals with the problems involved in the vaporisation of fuels of different types and the influence of the physical characteristics of the fuels on these problems.

Part 3 occupies about one half of the book and deals in full detail with the physical and chemical tests employed in evaluating liquid fuels. This section is particularly well written, the tests being carefully selected, the important details, which bear the *cachet* of practical experience, duly stressed and the correlation of the results of the chemical analysis with the behaviour of the fuel in the cylinder clearly (and in some cases graphically) set forth.

It seems ungrateful to criticize minor points in so excellent a book, but exception may be taken to the use of the term "hydroaromatic" as a synonym for "naphthenic" or "cycloparaffinoid" (p. 6). The property of viscosity hysteresis is not peculiar to Mexican oils (p. 113) while makeshift methods of estimating sulphur without using a bomb calorimeter are (except in a few specific cases) not only useless but misleading.

Mr. Moore's book is to be unreservedly recommended to chemists and engineers interested in this subject.

F. B. T.

PETROLEUM NOTES AND CORRESPONDENCE.

It has been decided to open columns in the Journal to be devoted to general petroleum notes and to correspondence. Members of the Institution are invited to contribute thereto as occasion warrants.

ANNUAL REPORT, 1920.

THE Institution, on December 31st, 1920, had a Membership as follows:

Honorary Members	7
Members	229
Associate Members	93
Students	35
Associates	23
Total	387

This is an addition over 1919 of 100 members, and 33 candidates were awaiting election. Several members, residing abroad, elected in the latter part of the year, have not yet had time to pay their subscriptions and therefore are not included in this figure.

The new List of Members, brought up to March 31st, 1921, will be issued with Journal 26.

The Statement of Accounts shows that the financial position is a strong one. This is mainly due to the generous subscriptions received from several of the leading oil companies, and others, and also to the increase in membership.

Expenses were incurred during the year in taking and in furnishing the new offices, including increased accommodation for our growing library; also an additional annual expenditure has been involved in the appointment of a Secretary and a Librarian. The corresponding benefit to the Institution has been great and we believe is much appreciated by members.

The expenses attending the change of offices from 17, Gracechurch Street, and furnishing the premises at 5, John Street, amount to £252 11s. 6d.

In addition a considerable sum of money has been expended in the purchase of new books for the Library and in the binding of periodicals, etc.

A new Edition of the Library Catalogue, brought up to date, is being prepared and will be issued to the members in due course. The compilation of this List has been held back owing to the increasing number of new books it is contemplated will be purchased this year.

The revenue derived from the sales of the Journal amounted to £212 12s. 11d., as compared with £146 4s. 6d. for the previous year, and the amount received in payment of advertisements shows a marked increase owing to the extended circulation of the Journal.

The Council consider that this is a very satisfactory feature in connection with the progress of the Institution, as it indicates the interest taken by others than members in its activity.

Professor John Samuel Strafford Brame, F.I.C., F.C.S., has been elected President for the ensuing year.

The Rt. Hon. Viscount Cowdray of Cowdray and Sir Thomas H. Holland, K.C.I.E., D.Sc., F.R.S., Vice-Presidents, retire, and, being eligible, have been re-elected; and Herbert Barringer, M.Inst.C.E., M.I.Mech.E., M.I.N.A., Sir George Beilby, LL.D., F.R.S., Sir John T. Cargill, Bart., and Arthur W. Eastlake, M.I.Min.E., A.M.I.Mech.E., have been unanimously elected as Vice-Presidents.

The Institution is represented on the :—

Conjoint Board of Scientific Societies.

Committees on the Extended Use of Oil Fuel in the Mercantile Marine, appointed by H.M. Petroleum Department.

Committee of the Imperial Mineral Resources Bureau on Abstracts, Publications and Libraries, and on Petroleum.

Committees, British Engineering Standards Association.

Committees, Sulphonated Oils Committee.

The Institution's Library at 5, John Street, Adelphi, London, W.C. 2, is open from 11 a.m. to 4 p.m. where members will be able to consult the books, together with the current scientific literature.

Further exchanges of our Publications for Journals of other Scientific Societies have been arranged.

Since the last Annual Meeting the Honorary Editor reports that four numbers of the Journal, each containing two papers, have been published.

During the year a series of Popular Oil Lectures were delivered by members of the Institution at the Oil Section of the Victory Exhibition, held at the Crystal Palace as under :—

June 30th. General Introductory Lecture, by Sir Frederick W. Black, K.C.B., B.A.(Lond.).

July 7th. "Wild Catting," by E. H. Cunningham-Craig, B.A., F.R.S.E., F.G.S.

July 14th. "Oil Storage, Transport and Distribution," by Herbert Barringer, M.Inst.C.E., M.I.N.A., M.Inst.Mar.Eng.

September 1st. "Oil Prospecting," by George Howell, F.G.S., F.R.G.S.

September 8th. "Petroleum Refining," by A. E. Dunstan, D.Sc., F.I.C., F.C.S.

September 15th. "Utilization of Volatile Oils," by W. R. Ormandy, D.Sc., F.C.S.

September 22nd. "Utilization of Heavy Oils," by Professor J. S. S. Brame, F.I.C., F.C.S.

The Council has arranged to publish in book form the above Series of Lectures rewritten and illustrated with some ninety-two diagrams and plates. The work will be issued as a Popular Petroleum Book with Glossary, Statistical Tables (including various weights and measures for technical reference) and Bibliography, and other useful information.

The Institution has to deplore the death of five members, namely: Mr. Edwin R. Blundstone, B.A.(Cantab.), F.G.S., Admiral-of-the-Fleet Rt. Hon. Lord Fisher of Kilverstone, G.C.B., O.M., G.C.V.O., Mr. James Hamilton, Mr. A. B. Hawkins, and Mr. W. Rogers, and short obituary notices will be found in the Journals.

The Second Annual Dinner, held on March 23rd, 1920, was attended by some 153 members and guests.

The Council of the Royal Society of Arts have continued to afford the Institution the privilege of holding its meetings at their House.

The Council wish to express their appreciation of, and thanks for valuable service rendered to the Institution by the Honorary Treasurer, Sir William Plender, G.B.E., and the Honorary Auditors, Messrs. Price, Waterhouse & Co.

It is with the greatest regret that the Council learn that Mr. W. H. Dalton, F.G.S., has resigned his position as Honorary Editor. The services which he rendered to the Institution were invaluable and he has been unanimously elected an Honorary Member of the Institution.

The Honorary Auditors, Messrs. Price, Waterhouse & Co., retire, and being eligible, have kindly consented to agree to their re-election.

By order of the Council,

ARTHUR W. EASTLAKE,
Honorary Secretary.

REVENUE ACCOUNT for Year ended 31st December, 1920.

	£	s.	d.
To Salaries	506	8	4
„ Rent, Rates, etc.	223	13	3
„ Printing and Stationery	832	7	11
„ Postage	56	7	2
„ Hire of Hall for Meetings and Expenses of Meetings ..	114	14	0
„ Sundry Expenses	178	8	4
„ Expenses at the Crystal Palace	28	15	3
„ Balance carried to Balance Sheet	495	10	8
	£2436	4	11

	£	s.	d.
By Subscriptions :—			
Members	831	1	6
Special	1285	10	0
„ Interest and Dividends	62	15	0
„ Sale of Journal	189	19	9
„ Advertisements in Journal	66	18	8
	£2436	4	11

BALANCE SHEET, as at 31st December, 1920.

LIABILITIES.

	£	s.	d.	£	s.	d.	£	s.	d.
To Capital of the Institution, under Bye-law 14, viz. :—									
Life Membership Fund, per last Account				381	10	0			
Entrance Fees, per last Account	268	15	0						
Additions during year ..	175	7	0						
				444	2	0			
Donations received during the year				250	0	0			
							1075	12	0
„ Sundry Creditors							642	1	6
„ Subscriptions paid in advance							177	9	0
„ Revenue Account—									
Balance, 31st December, 1919				116	13	11			
Deduct—Subscriptions prior to 31st December, 1919, now written off, less arrears recovered				64	1	0			
				52	12	11			
Balance for the year, as per Account above				495	10	8			
							548	3	7
							£2443	6	1

ASSETS.

	£ s. d.	£ s. d.
By Investments, at Cost—		
£464 6 6 London County 3% Consolidated Stock	375 0 0	
£100 0 0 War Loan 5% 1929/47 ..	95 0 0	
£50 0 0 War Bonds 1927	50 0 0	
£150 0 0 Birmingham Corporation 6% Stock	146 16 0	
(*Note.*—Market price of above Investments on 31/12/20=£511 13s. 3d.)		666 16 0
,, Office Furniture (excluding presentations) per last Account	85 0 8	
Additions during year	256 4 4	
		341 5 0
,, Library (excluding presentations) ..		77 17 6
,, Subscriptions (1920) outstanding at date and considered collectible		192 3 0
,, Sundry Debtors		192 3 0
,, Cash on Deposit		69 10 8
,, Cash at Bank and in Hand		900 0 0
		195 13 11
		£2443 6 1

F. W. BLACK,
ARTHUR W. EASTLAKE } *Members of Council.*

We have examined the above Balance Sheet with the Books of the Institution, and having obtained all the information and explanations we have required, we are of the opinion that such Balance Sheet is properly drawn up so as to exhibit a true and correct view of the state of the Institution's affairs, according to the best of our information and the explanations given to us, and as shown by the Books of the Institution.

PRICE, WATERHOUSE & CO.

3, FREDERICK'S PLACE,
OLD JEWRY, LONDON, E.C. 2.

10*th March*, 1921.

The Fifty-first General Meeting of the Institution was held in the Room of the Royal Society of Arts, John Street, Adelphi, W.C., on Tuesday evening, December 14th, 1920, Dr. W. R. Ormandy (in the absence of the President, Sir Frederick Black) occupying the Chair.

The Secretary announced the names of the newly elected members.

In the absence of the author, the following paper was read by **Mr. A. W. Davson** :—

Boring in Palestine.

By Captain Paul H. Mangin.

Introduction.

In presenting the following paper to Members of this Institution, the author is fully aware of the fact that data obtained from military sources and under war-time conditions often lose much of their interest and value when an attempt is made to apply them to normal commercial enterprise.

It is essential, when dealing with work of the nature of well-boring, that general conditions in the field be made to approach the ideal, as nearly as circumstances permit, and every effort taken to reduce the handicap under which the driller inevitably works in a strange country, and under military control.

Generally speaking, methods cannot be entirely modified to suit military requirements, and general routine orders have no appreciable effect upon the fundamental principles employed. Hence, it may reasonably be assumed that information collected from such operations has usually a direct application to peace-time conditions, and loses little of its interest to the civilian engineer.

The difficulties met with in boring for water in Palestine were manifold; those most easily overcome being due to the treacherous nature of the sands, which form the bulk of the formation to be penetrated. The remainder originated in the expectation, by the superior control, of "miracles" which did not come off; and its failure to appreciate the psychological factors governing men engaged on this type of work under existing circumstances—a failure to some extent inevitable in war-time.

The personnel of the section at its formation in April, 1917, consisted of sappers, bricklayers, carpenters, clerks and a small sprinkling of

smiths and mechanics, detailed willy-nilly from the various field companies. These men had no previous knowledge of well drilling, and the officer placed in charge made it very clear that his own qualifications for the position were confined to having administrated the putting down of a hand bore in the Kharga Oasis. Nine of the men referred to above formed the nucleus of the section throughout, and were reinforced later by others who volunteered for the work and were given some initial instruction by the author before they joined the section, of which he took charge in August.

The methods utilized in the training of the personnel of the section from the early stages to the time when the majority could be entrusted to carry out work on detachment, and report their progress and requirements intelligibly, will, the author understands, be referred to in a paper to be read in the near future, before this Institution.

With one notable exception, the plant and tools available had been purchased without reference to the nature of the country or the kind of geological formation to be dealt with, and under conditions where, although every inch of the bores had to be cased as fast as drilling proceeded, not a single machine was provided with any means of handling casing.

There was, however, neither time nor opportunity to do more than make the best of what material was available at the moment, and really remarkable ingenuity was often shown by the N.C.O.'s and men in obtaining results much in excess of the normal capacity of the plant.

As time went on, a considerable quantity of plant and tools captured from the enemy became available, and much of this was adapted to the requirements of the situation, even to the extent of adapting a rig designed for use with "free-falls" to use the wire line, while a wider range of action became possible owing to the lighter weight and simpler design of the Austrian or German machines.

It must be left in the hands of those competent to judge to place a correct valuation on the Section's work.

The facts are briefly as follows:—

In a period of exactly two years thirty N.C.O.'s and men on the strength of the Section were trained in various capacities, largely as drillers; about 5,500 feet of hole was drilled of various diameters from 5 inches to 10 inches, and the aggregate daily output from all wells amounted to 1,500,000 gallons. In addition, the greatest care was taken in keeping records of the holes drilled and retaining typical samples of the formations met with, together with other useful data.

Geology and Topography.

The country of Palestine, whether regarded superficially or from

the point of view of the engineer in search of water, falls naturally into two well-marked divisions—the hill country and the maritime plains.

Little is known of the underground conditions existing in the former, and water supplies are scarce and precarious; in the latter water is plentiful, and can be reached by shallow borings, at a depth depending, in most cases, on the height of the location above mean sea-level and the distance from the coast. North of Haifa, however, conditions are less favourable, and conform more closely to those existing in the hill country.

The following remarks, therefore, should be understood to apply principally to the Plain Country lying between the Egyptian frontier at Rafah and Mount Carmel.

Forty-five bores to depths ranging from 100 to 300 feet were completed in this area, so that the conditions bearing on the underground water supplies may be said to be known with considerable accuracy, local variations of frequent occurrence notwithstanding.

The geological formations met with are almost uniformly unstable, and consist usually of calcareous sands of varying degrees of fineness.

Exceptions to this rule occur, and take the form of clay beds, thick deposits of marl, lenticular beds of siliceous sands and, most commonly, thin strata formed by the agglomeration of calcareous sands into nodules and larger masses of soft sandstone. Such exceptional strata are, however, easy to negotiate with the common forms of percussion boring plant; it is to the more regular formations that the greater interest attaches, owing to the exceptional difficulties often met with in penetrating them, difficulties which were aggravated in the present instances by the limited capacity of the plant and tools available.

In many cases the presence of water in sufficient quantity could be counted on with certainty, but the problems involved in completing the bore to the necessary depth, and with a diameter sufficient to accommodate the pump were none too easy of solution; while in several instances these initial difficulties having been successfully overcome, the nature of the formations was such that troubles with sand-screens seriously delayed completion of the well.

The depth to which it is necessary to bore, bears a direct relationship to the height of the location above M.S.L., but the level of the water table, referred to M.S.L., is lower near the coast and rises in proportion to the distance from the sea.

Beneath certain fertile areas, such as those of Ludd, Wilhelma, etc., underlying clay beds appear to hold up the water to a level consider-

ably above the normal, which fact possibly accounts for the marked fertility of the areas concerned.

Salt water, of varying degrees of salinity, is sometimes met with, and under certain conditions the water is permanently hard to such a degree as to render it unfit for almost any purpose. The areas thus affected are usually small, and two wells situated only a short distance apart may produce fresh and salt water respectively, while wells located near the edge of the affected area will produce fresh and salt water alternately particularly in the cases where the capacity of the pump is in excess of that of the well. Generally speaking, however, the quality of the water found is good, with a salinity of 30 parts or less per 100,000, and a total hardness under 25 degrees. At El Arish a maximum sodium chloride content of 200 parts per 100,000 was reached, while a total hardness of 87 degrees was registered in two bores put down near Ludd, but these are exceptional figures, and are far above the normal for the greater part of this country.

In all, 45 bores were completed, full particulars of which will be found in the attached tables, A and B, while the map shows the locations of all but a few unimportant wells.

Costs

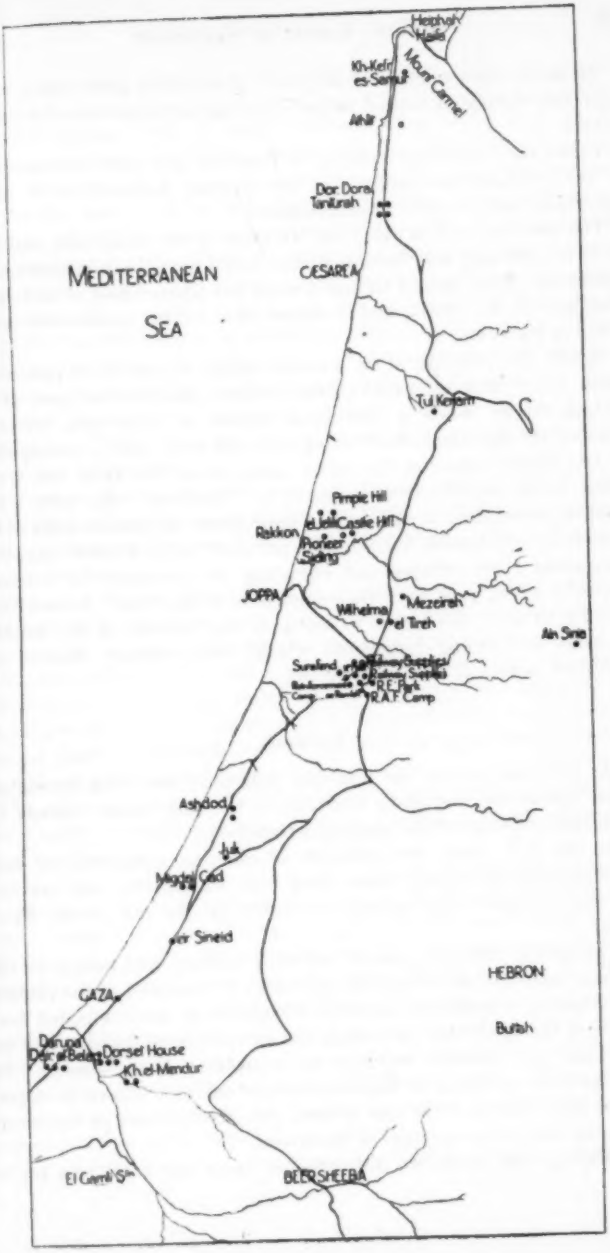
In estimating the cost of the operations every reasonable item was debited against each rig, including rations, separation allowances, overhead charges, etc.

Under conditions of Active Service less attention is naturally paid to finance than to rapid and successful completion of the work, and for this reason the cost per foot was probably somewhat in excess of what it would be under civilian control; on the other hand, the personnel employed were, at the beginning, entirely inexperienced in this class of work, and the early bores should be regarded largely as instructional.

Plant

Five types of drilling rig were in use simultaneously by the Boring Section, which materially increased the difficulties of training the operators.

One plant only was of the type entirely suitable for the formations met with—a hydraulic-percussion machine using a mud flush with a short stroke. The remainder were of the usual "portable" kind, including 2 Star Rigs, 1 Columbia Driller, several German power-driven plants using "free-falls," and a number of similar rigs operated by hand.


Haifa
Mount Carmel
Athlit
Dor Dora
Tantura
MEDITERRANEAN
SEA
CAESAREA
Tul Keram
Pimple Hill
Castle Hill
Rakkon
Pioneer Siding
JOPPA
Wilhelma
Mezzerah
Ain Sinia
Sarafand
R.A.F. Camp
Ashdod
Ajjur
Magdal Gad
Sinaid
HEBRON
GAZA
Burah
Dorset House
Khel-Mendur
El Ganal Stn
BEERSHEBA

All these types would probably have given fairly good results when operating through a limited range of geological formations of a simple nature.

Under the conditions existing in Palestine and with the exception of the hydraulic-percussion rig, they proved, however, to be slow, uncertain, and generally unsatisfactory.

The latter proved in every way suitable to the conditions, and had tools of sufficient size been available would have been in continuous operation. This class of rig has a much less limited field of usefulness than any of the others, and is almost ideal for the treacherous sands found in Palestine.

Briefly, the principle of its action is similar to that of all percussion plant, but a short and rapid stroke is used in place of the usual 24- to 30-inch stroke, while a continuous stream of mud-laden water is pumped through the hollow boring-rods and tools, which, issuing close to the cutting edges of the latter, keeps them free from the heavy sands which would otherwise serve to "cushion" the blow. The pressure maintained is sufficient to impregnate the porous walls of the bore to a considerable horizontal depth with finely divided clay, thus preventing their collapse and obviating the necessity for inserting casing or lining pipe until the completion of the bore. It was found possible to carry small bores to depths of over 200 feet by this method, in loose and caving formations which, with ordinary class of rig, collapsed as fast as they were drilled.

Methods

As indicated above, the principal difficulties met with throughout these operations were both traceable to the same cause, namely the treacherous nature of the sands penetrated.

In the first place, the difficulty of carrying comparatively large diameter casing through these sands was considerable and can only be said to have been entirely overcome by the use of the Fauck plant.

The second difficulty proved still more baffling, and cannot be said to have been entirely solved for all cases; it consisted in the problem of obtaining a sufficient quantity of water from the completed bore, while at the same time preventing the entry of large quantities of fine sand and silt; in other words, it was a problem of sand-screens. The satisfactory operation of these accessories has been shown to depend upon three factors: the rate of flow, the effective area of the screen, and the size of the openings in the screen.

Dealing with these two difficulties in order and neglecting for the

moment the results obtained with the Fauck system, it was recognized from the commencement that in order to negotiate these formations with the ordinary type of plant, two conditions would have to be fulfilled or produced artificially. In the first place, such formations not being susceptible to the percussive action of the tools, the portion forming the bottom of the bore-hole for the time being must be so tempered with other material as to render it capable of being drilled, and of maintaining the walls of the bore intact for a reasonable distance ahead of the casing. The material most suitable for this purpose and most commonly available is clay, and this should be free from sands or other materials likely to neutralize its effect. In the course of time as drilling proceeds the introduction of clay produces an artificial stratum at the bottom of the bore which is comparatively easy to deal with, and possesses the necessary adhesive qualities to enable the walls of the bore to support themselves until it is possible to lower the casing within them.

A small problem arises when any considerable depth of water exists in the bore, as the time taken by the clay to reach bottom under these conditions is excessive, and may amount to many hours even in a shallow boring.

Where the depth of water is not too great the clay may be made up into hard balls, which can usually be depended upon to hold together long enough to traverse the intervening water before breaking up.

An alternative method employed where the depth of water is considerable is to fill a small bailer with clay, having first replaced the clack-valve by a few thicknesses of stout paper. The bailer is then lowered gently to the bottom of the hole and the paper bottom broken out, releasing the load of clay.

This process is repeated until sufficient clay has been introduced, the quantity depending principally upon the nature of the sands and the size of the bore.

Many experiments were carried out, when circumstances permitted, to determine the best method of dealing with these unstable formations. Under certain conditions, it was found that small casing would follow a water-jet to considerable depths. No power-pumps were available, and the jet was coupled by means of 1-inch piping to one or more hand-pumps; once the bore became filled with water sufficiently rapid circulation could be maintained to carry the greater part of the sand loosened by the jet to surface, and the casing sank as the sand upon which it was supported was gradually removed. This method was also notably successful for clearing the casing of sand, which had gained entry owing to damaged sand-screens.

This method, however, presupposes a sufficient quantity of water,

which was not often available, and further attempts to find a rapid and economical means of boring were made.

Among dry methods, the most promising appeared to be the use of "Meyer" surface augers, and a bore was put down to a depth of 135 feet with one of these. The tool used measured about 20 feet in length, and made a hole suitable for 16 cms. inside diameter casing.

It was found that, so long as the formations consisted of dry sands, the limiting factor was the difficulty of keeping the bore vertical; as soon as a depth of about 60 to 70 feet was reached great difficulty was experienced in preventing the auger from "side-tracking." This was largely due to the light section rods in use, which were not stiff enough to give proper control over the tool. As soon as the bore departed more than a few degrees from the vertical, caving took place from the overhanging wall, and the tools had to be removed at once to prevent their becoming buried.

With special care, the maximum depth stated above was reached and casing inserted, the latter operation being difficult owing to the crookedness of the bore. Guides were therefore made and fitted above the auger, but changes in the military situation made it impossible to try these out.

It seems probable, from the information gained, that, with properly designed augers, fitted with guides, good results might be obtained, but it is only under certain conditions that the method is permissible.

As soon as water is reached casing must be inserted, as caving is inevitable. A further difficulty is presented owing to the fact that, while it is imperative that the sands to be penetrated are nearly dry, hard clay beds can only be negotiated in the presence of water, of which there must be sufficient to soften the clay and to lubricate the cutting edge of the tool. Hence, where the two classes of formation alternate frequently, the conditions favourable to the one are inimical to the other.

The above, and most other improvised methods, are useful only where the diameter of the casing to be inserted does not exceed five or six inches. For dealing with larger bores, where nothing but the standard percussive type of rig is available, the introduction of clay into the bore often in very large quantities is necessary, except where the nature of the formations is such that the casing will follow the bailer or sand-pump with occasional assistance in the way of loading. Even then, it is usually necessary to complete the bore by driving the casing—a most pernicious method which can never be recommended, even where heavy section "drive pipe" is available. It is hardly necessary to add that "flush" or inserted joint casing gives the best

results under those conditions and, in the latter case, driving should be strenuously avoided. Unfortunately, the conditions obtaining during the war rendered it impossible to pick and choose with regard to casing, and most of the bores in Palestine were lined with American collared pipe.

A word of warning is necessary here with regard to the use of clay to assist the drilling. Such clay accumulates in the bore, i.e. the whole cannot be recovered in the ordinary process of bailing between runs, and it is essential that the bulk of it be removed after completion of the bore, and before insertion of the sand-screens. Very serious difficulty was often met with owing to the choking of screens by clay left in the bore, and in the class of formation under discussion it is usually impossible to withdraw the screens without permitting the sand to rise into the casing, from which it is often a work of weeks to remove it. In some cases the screens became fast in the bore, and resisted all efforts to dislodge them.

The problem of removal of the surplus clay is, however, by no means a simple one; as is well known, long continued bailing will often start a lateral movement in the sands, tending to shear the casing, and if this does not actually part it will be carried out of the vertical sufficiently to prohibit the installation of the pump-tubing, and the bore will need to be drilled anew.

There is no royal road to success in these operations, but unlimited patience, unremitting attention to detail, and careful observation will usually ensure a fair proportion of successful bores, particularly where conditions admit of preliminary trial borings.

As stated in the earlier part of this paper, of the many types of portable drilling plant represented among those in use by the Boring Section, the most effective was the hydraulic percussion rig; using a short and rapid stroke in conjunction with a "mud-flush" circulating system. Possibly a rotary system, using the ordinary "fish-tail" bit with the mud-flush would have given equally good results, but the conditions were such that lightness and portability were of primary importance, and the weight of a rotary plant of the same capacity would have been prohibitive, except on L. of C. The expression "Rotary" is used here in its broadest sense, to include all methods which are not percussive in action.

Designs for such a plant were actually prepared in Cairo, and arrangements had been made for a local engineering works to manufacture one, when the proposition was vetoed by G.H.Q. without reason given.

The usefulness of the Hydraulic Percussion Plant was seriously curtailed owing to the fact that no tools suitable for the larger sizes of

casing—8 inch and 10 inch diameter—could be obtained, the largest bit available being about 9½ inches in width, which with this system is too small for collared pipe of 8 inches inside diameter.

Hence, it was only in cases where the required yield was not more than 1000/1200 gallons per hour that this plant could be employed, and in such cases it was usually found that the hand-rigs gave better service, having regard to transport difficulties, and the necessity for concealment.

A considerable number of experiments were carried out with the object of determining the best consistency for the "slurry." Too thin a mixture naturally leads to caving of the walls of the bore, while a high percentage of clay will form a deposit on the sides of the hole, which rapidly reduces the diameter, and, in extreme cases, may necessitate reaming before inserting the casing.

The crux of the whole problem is the difficulty of ensuring a uniform quality of clay, from which all arenaceous matter must be extracted—a practical impossibility in many instances. It was found that, where time is an important factor, the only solution was to use a much stronger mixture than actually necessary, and to insert a smaller size of casing than would be used for the same size of bore, drilled by "dry" methods. It is demonstrable, however, that under scientific control, with properly prepared slurry, the percentage of clay in the mixture can, and should be, maintained within very small limits, with a resulting remarkable increase in efficiency.

The means employed in the actual drilling of the well is not, however, a matter of great moment once local conditions are thoroughly understood, and the drillers have learnt, on one or two holes, the best way out of the various difficulties which occur. The real problem is the successful operation of the well, including, and with special reference to, the fixing of the sand-screens and their maintenance under varying rates of flow.

The sands met with in Palestine vary through all degrees of fineness, the most plentiful supplies of water being often found in sand beds containing a large percentage of what can only be described as a calcareous dust.

Where the proportion of coarser material is high, a natural filter-bed will often form, and after a more or less considerable quantity of the finer elements have been pumped out, the coarser sands, collecting round the screen form a second, and very efficient, protection against the entry of the finer particles. In this manner, several wells, which at first gave endless trouble owing to the entry of sand, finally cleared themselves and yielded up to the full capacity of the pump.

Under these conditions minor subsequent disturbances will some-

times start a further flow of sand, and the only remedy is to shut down the revolutions of the pump until the trouble ceases.

In extreme cases, where nearly the whole of the sand is very fine in texture, the problem of obtaining a reasonable supply of water, while excluding all but a small quantity of sand is one of very great difficulty.

Except by the use of an air-lift system, no complete solution has yet been arrived at. The most popular method, with the professional driller, is to pull the casing, and make a fresh start some distance from the original site. Owing to the very variable nature of most sands, even over quite small areas, this method is often successful.

There are, however, conditions which do not permit of the adoption of this means of overcoming the difficulty, and although it is impossible to ensure success under all circumstances, attention to the following points will go a long way towards ensuring efficient operation.

It is of prime importance—and this is indeed the key to the whole problem—that the rate of flow of water through unit area of the screen shall not exceed a certain maximum.

The maximum figure will vary with different classes of sand, and may often not exceed a velocity of one inch per second, while in many cases it must be very much less.

When, as often occurs under military control, the yield required from the bore is fixed by circumstances at a definite figure, the rate of flow can only be adjusted by varying the effective area of the screen, this being determined by three factors :—

1. The total length of the screen (this often determined by the thickness of the water-bearing stratum).
2. The diameter of the screen ; and
3. The "opening factor" of the material used in its construction.

In cases where the total thickness of the water-bearing stratum is small, the length of the screen should be at least equal to this thickness. Where conditions admit of increasing the length of the screen to obtain greater area, a proportional increase in diameter is also desirable, as a long screen of small diameter does not give the best results, owing, probably, to the fact that the flow of water through the screen varies at different levels, and the whole of the available area is not, therefore, equally operative.

The opening factor of the screen varies according to the method of construction. This is a point that often receives insufficient attention, and in the commoner form of screens the opening factor may be very small indeed.

It is and will never exceed 0.56 for ordinary woven cloth.

It should be remembered, however, that the opening factor of the slotted frame, which carries the cloth, is often as low as 0.40, so that the net effective area of the screen under these circumstances will be less than one quarter of the gross area.

A yield of one thousand gallons per hour through such a screen will produce a flow-velocity of approximately 0.05 inches per second, and it was found when using reciprocating pumps (i.e. when flow only occurs during half of each revolution, doubling in effect the velocity through the screens) that this figure was a maximum for many of the sands encountered. Various authorities give from two to three inches per second as a safe figure, but it was found impossible to approach this in Palestine, with the class of screen available. Even as it was in a few cases it was found necessary to take further precautions, and the space round the screen was filled in with graded sand, on the "Maury" principle.

Where a well is expected to be in use throughout the year, it is important that the top of the screens should be a sufficient distance below the lowest possible level to which the surface of the water-table may be expected to fall in the dry season, and the consequent reduction in effective area almost invariably leads to the entry of sand, with the result that the well may be useless at a time when water is most urgently required.

The whole question of the satisfactory operation of a bored well is so much a matter of experience and knowledge of local conditions that little information of practical value can be obtained from the very scanty literature on the subject. There appears to be no work extant dealing with the practical details of the drilling and operating of wells of this type; what little information is available from books is either inserted casually in a comprehensive work on water supply as a whole or is found in the publications of various manufacturers or contractors, whose sole object is the advertisement of their own plant, or methods, information on other types of plant or other means of boring wells being carefully withheld.

Until quite recently, the practical driller has been invariably drawn from a class which, by education and temperament, is hopelessly incapable of putting the results of experience into readable form, or even of forming a clear conception of the principles which underlie the various methods he employs; hence, much valuable information is irrevocably lost, or remains in the hands of contractors, who have the best of reasons for withholding it from publication.

TABLE "A"

New Bores

Bore.	Location.	Depth (feet)	Av. feet per hour	Yield in G.P.H.	Remarks.
—	El Arish	45·0	—	2000	Abandoned: salinity 200 pts. per 100000.
—	Deir el Belah	73·0	0·46	Nil	Abandoned: salinity 200 pts. per 100000.
1	El Mendur	108·7	0·29	1600	
1	Dorset House	86·5	0·26	1200	
2	" "	170·6	0·36	1200	
3	" "	95·0	0·38	1200	
4	" "	71·0	0·13	Nil	Abandoned: tool lost in bore.
2	El Mendur	128·75	0·18	1600	
1	Old Rafa	92·0	0·28	Nil	Abandoned owing to sand troubles.
2	"	49·0	—	Nil	Abandoned: no longer required.
—	Julis	166·0	0·40	500	
1	Esdud (Ashdod)	90·0	0·50	3500	
2	" "	95·0	0·47	3500	
—	Surafend (Ludd)	172·0	0·67	3200	
—	Reinforcement Camp (Ludd)	200·0	0·90	500	Abandoned: water too hard.
1	Mejdel (Migdal)	203·0	0·47	400	
2	" "	200·5	0·03	400	
2	Reinforcement Camp (Ludd)	304·0	0·50	500	Abandoned: water too hard.
—	Ramleh Aerodrome	215·6	0·52	Nil	Abandoned: probable depth of water beyond capacity of pump.
—	"Pioneer Siding" (Jelil)	161·0	0·52	1100	
1	Ludd Rly. Station	203·0	0·43	800	Abandoned: yield insufficient.
—	El Mezirah	140·0	0·28	500	Supply partly shut off by 10 in. casing; no jack sufficiently powerful to lift.
1	"Castle Hill" (Mulobbis)	104·5	0·70	1100	
2	do. do.	111·7	0·09	1100	
2	Ludd Rly Station	139·0	0·22	300	Supply insufficient.
—	"Pimple Hill" (Jelil)	185·5	0·76	1100	
—	Ludd: Trial boring	137·0	—	—	Put down with Meyer surface auger.
1	Deir el Belah	183·0	0·24	3000	
—	Ain Sinia	140·5	0·46	Nil	Bore abandoned.
2	Deir el Belah	188·0	0·66	3000	
—	Tantura	53·0	0·73	3500	Trial boring.
1	"	47·0	0·75	3500	Salinity too high.
2	"	39·0	0·46	2500	Salinity 77 pts. per 100000.
3	"	37·5	0·87	3500	Salinity 77 pts. per 100000.

TABLE "A"

NEW BORES

Bore.	Location.	Depth (feet)	Av. feet per hour	Yield in G.P.H.	Remarks.
—	Tul-Keram	217·5	0·79	1350	
3	Ludd Rly. Station	145·0	0·68	3000	
4	" "	147·0	0·68	1800	
3	Rafa "	265·5	0·72	Supply not tested.	Salinity 73·7 ft. per 100000.
—	Kefr-es-Samir (Haifa)	55·5	0·40	—	Abandoned: yield insufficient.
—	Athlit	65·0	0·16	250	Abandoned.

TABLE "B"

BORES IN WELLS

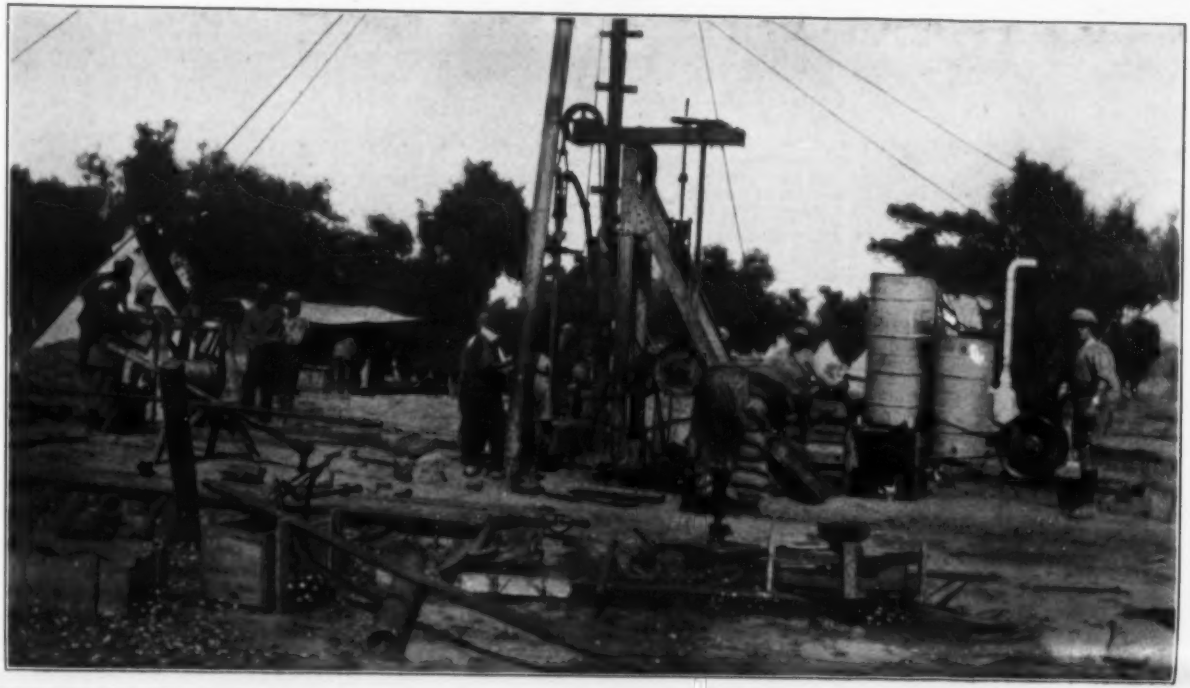
Location.	Depth of bore below well bottom.		Yield G.P.H.	Remarks.
Et Tireh	34·5	..	3500	No improvement in yield.
No. 2 Well (Ludd)	46·0	..	4000	Whole of yield from bore.
Wilhelma	70·0	..	4000	Original bore silted up; whole yield from bore.
No. 7 Well (Ludd)	55·0	..	?	Yield up to full capacity of pump: about 4000 G.P.H.
El Jelil	48·0	..	5000	

In introducing the slides **Mr. Davson** said that:

Fig. 2 showed the Fauck rig, to which the author referred at some length, in use with a 5 h.p. engine.

Fig. 3 showed the Draw Works of the German rigs. These rigs were designed for depths of about 300–400 feet, and bores of small diameter. They were of very simple construction and built throughout of steel channel plates and angles. They were arranged for external driving by belting from oil steam or other engines. Only one spool was provided for all purposes; this was driven from the countershaft by means of gearing; the countershaft being driven directly from the engine pulley by means of a 3-in. leather belt. The countershaft carried three belt pulleys, each 36 in. in diameter, the centre pulley was loose on the shaft and the remaining two operated the hoisting drum and walking beam, respectively. The belt was moved from one pulley to the next by means of the usual striking gear, the inmost pulley of the three operated the hoisting drum by

Fig. 2.



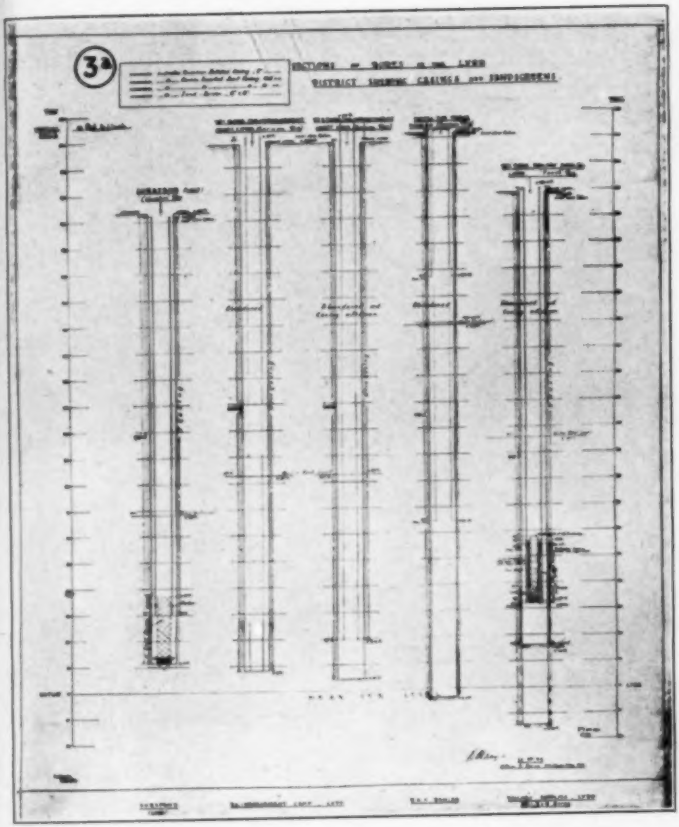


FIG. 4.

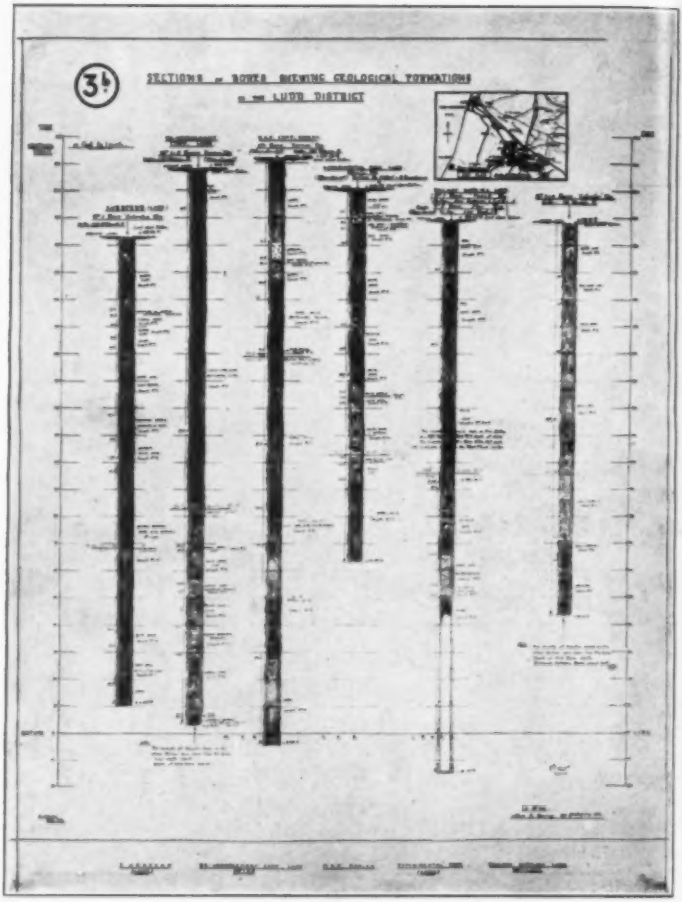

34
SECTIONS OF BORES SHEWING GEOLOGICAL FORMATIONS
IN THE LUDD DISTRICT

FIG. 5.

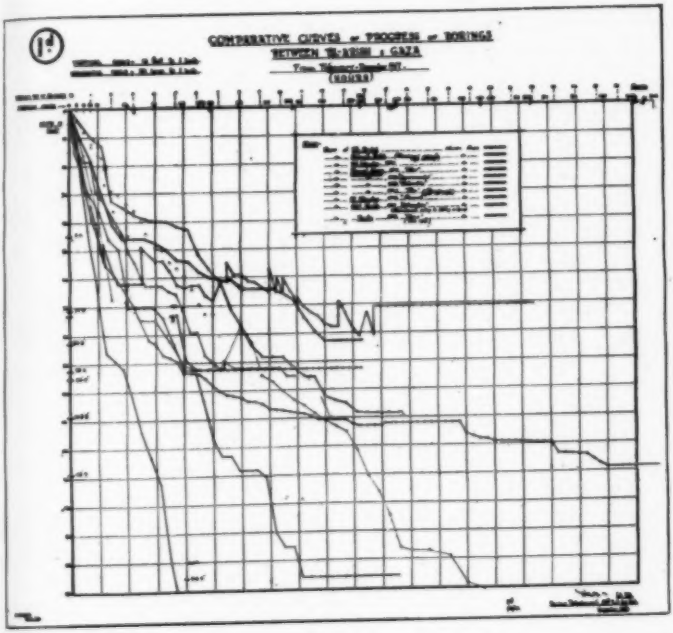


FIG. 6.

means of spare gearing—the driving pinion being attached directly to the boss pulley.

The countershaft was extended in both directions to take the crank handle, enabling hoisting to be done by hand if necessary.

The walking beam was slung about 6 in. forward of its centre, and was operated by the usual crank fitment, its stroke could be varied within certain limits to suit different conditions of drilling. A quadrant was mounted on the forward end of the beam in order to give a truly vertical movement to the drill chain and poles fed by means of a temper screw.

The drilling tools were operated through hollow iron drill poles on the Russian "Free-fall" system.

A simple and very effective method of utilising this plant for bores up to 200 ft. was by means of a slip rope 1¼ in. manilla, fitted to an American rope socket, and with a substitute from the American socket to the German sinker bar.

Figures 4–6 indicated the system of record keeping. Records were kept from the earliest days, when the Section was engaged in putting down hand bores, and the system initiated. Under the author, the complete system developed, the work of development being left almost entirely in the hands of Mr. Hendra, a surveyor to whom much credit was due. Mr. Davson said that his own interest and experience as to the value of records was primarily concerned with the value of logs and records in training men, but it was not proposed to emphasise or develop this point here, as it would be briefly referred to on another occasion. The other uses of these records were to facilitate putting down further bores in a district; to collect data of possible geological value and, from the Section's standpoint, to safeguard their interests and save trouble in supplying the varied information required. As a safeguard, these records served their purpose well. Due to the policy of superior control referred to by the author, minor controls were continuously changing and the established system, which these records indicated, prevented in many cases the complete overthrow of the policy adopted which would undoubtedly have taken place otherwise. In addition to these direct controls the work was conducted in all areas, resulting in orders and requests for information which had to be met.

It must be remembered that the information required was often from people who had no knowledge of well-drilling, and to whom a description of a finished well would mean nothing. But all ranks and all units in the Army were taught to understand a sketch. Hence over elaboration was almost impossible in this direction, and the methods developed enabled a sketch to be taken from one or other

of the permanent records, which served to answer practically any type of question asked. The charts were divided into progress charts, casing and geological.

Bores in each district were as far as possible plotted on to the same chart, the plotting being done in relation to mean sea-level for the sake of rapid comparison.

A Progress Chart was kept and a complete vindication of this policy of records was, it is thought, given when after the principle had been developed for over a year a Senior Officer, after seeing one of these charts, sent down orders that "In future records must be kept."

Fig. 4 showed casing Charts. In civil life these would probably be unnecessary, but for the reasons stated above they proved invaluable in the Army. They were of interest here as showing the various subterfuges necessary, under the existing circumstances, in utilising sand screens.

At first no screens were available, but constant sand pumping resulted in cleaning the bore, and a good supply of water was obtained. This method tried again later resulted in pressure of sand pushing the casing out of the vertical. Sand screens then became available, but the only means of fixing them to the bottom of the casing was by means of a packer.

Successful in some cases, in others the packer failed to maintain the screen in position, and pressure of sand forced it up into the bottom of the casing, whilst in one instance the screen was entirely lost.

Another difficulty encountered, as the author pointed out, was that the finer sands penetrated these single screens. Perforated casing covered with wire gauze and an internal screen was therefore tried and proved satisfactory in some cases. In others it was found necessary to fill between the screens with graded sand.

This did not prove a complete solution of the problem, as further bores treated in a similar manner did not give a yield equal to the capacity of the pump owing to the fact that the sand packed round the outside of the screen. To clear the screen by forcing water down was often impracticable as there was often insufficient water available for that purpose, whilst in one case, when this method was tried, it did not clear the screen. No final or standard solution can therefore be said to have been reached, proving the truth of the statement of one of your members who visited the work, namely, that "Every bore is a problem unto itself."

Fig. 5 showed one of the Geological Charts, the information derived from which enabled the general lie of the water-bearing sands to be determined, and the suggestion of underlying clay beds beneath

the fertile areas to be to some extent established. Moreover, later when the railway, after having the use of the Nile water as far as Rafa through the pipe-line, became very particular as to the salinity and hardness of the bore water offered them these charts proved of considerable value in arriving at the possibility of producing water from prospective bores of a low enough salinity to satisfy the railway authorities.

In conclusion, **Mr. A. W. Davson** asked permission to digress from the subject-matter of the paper for two minutes only. He felt the paper without its author to read it was rather like a play with the star absent from his interpretation of the chief part. In the present case the members had not the solace that the substitute might be equally good, because he could make no claims to mechanical engineering knowledge and could not lead them as the author would have with his practical knowledge of deep drilling to a full discussion of the morals which might be drawn from these miniature experiences in relation to problems arising in the broader fields of Petroleum Technology.

He believed that the author was not unknown to the members: he spoke briefly at a meeting a few months ago with the full force of a powerful personality. He therefore made no apology for throwing a picture of the author on the screen, to remind those who saw and heard him at the meeting referred to, and to introduce him to the remainder.

He was afraid the features were indistinguishable, but the author was in an attitude of thought typical of him, pondering the problem of how to turn a Turkish bore to the immediate use of the troops—a bore of which he had no particulars—and the principal interest attached to which was that it possessed three strings of casing. The author solved the problem rapidly and successfully. In reading the paper to the meeting, he pictured once again, as he would like the members to picture, a man accustomed to the larger problems involved in Petroleum Technology suddenly restricted both from the administrative and technical standpoint within the narrowest limits conceivable. He saw that man, having adjusted his focus to the new circumstances, weighing with infinite care the various conditions as they arose and assigning to each a specific value. He saw him with unlimited patience training his men, where circumstances permitted, in the elementary experiences of deep well-drilling, and by unremitting attention to detail and careful observation ensuring the fair proportion of successes which he considered his due.

Lastly, he saw a man with an unlimited enthusiasm for and concentration on the work on hand, whatever it might be, and he wished

it were possible to pass on to the members some of that enthusiasm with which the author infected all around him, and with which he felt sure the author would have inspired the present meeting had he been able to be present to read his paper this evening.

DISCUSSION.

The Chairman said the Publication Committee of the Institution hesitated at first whether a paper which was primarily devoted to drilling for water should be read before the Institution, which was associated more with drilling for oil, but the problems attached to drilling were so familiar in both cases and the experience of the author was so unique that it was felt that that experience might well be placed at the disposal of the members. He endorsed everything that Mr. Davson had said with regard to the author's personality, and, although the members much regretted that Captain Mangin was unable to read his paper personally, he was sure they would agree that the Institution had been very fortunate indeed to get such an able reader of the paper in the person of Mr. Davson, who had been on the spot and could add that live interest which could only come from anyone who had been associated with the subject with which the paper dealt.

Col. E. M. Paul (Deputy Director of Works, War Office; previously Director of Works and Chief Engineer, Egypt, during the war), in opening the discussion, said he had had the inestimable advantage of seeing the work carried out in Palestine which had been described by the author, as he occupied the position of Director of Works and acting Engineer-in-Chief for periods in 1917–18 under Lord Allenby; he therefore possessed a certain knowledge of the difficulties which had to be contended with from time to time and which had been mentioned to a small extent in the paper. A certain amount of well-boring was carried out in France with similar rigs to those employed in Palestine, a description of which was given in a paper recently read before the Institution of Civil Engineers. In France it was comparatively easy to get supplies of plant, and, when any part was broken, to replace it within a short space of time, but well-boring in an enemy country like Palestine was carried out under very different circumstances indeed. Palestine was hundreds of miles away from any place where plant could be obtained, and the engineers had to adapt whatever they could find on the spot—which was often little—to the object in view. He supposed the old world tradition of "making bricks without straw," in Egypt, obtained very much at

this time in Palestine, so far as well-boring plant was concerned. He much admired the ingenuity and skill with which the work was carried out. He was not well acquainted with the results obtained in France, but he felt convinced that the records obtained in Palestine over a period of two years would compare very favourably with those obtained in France under much better and easier circumstances. It might be said that the drilling crews were a very job lot, but the author and Mr. Davson took them in hand and trained them, and the results obtained were extraordinarily good. He thought very great credit was due to both those gentlemen for the way in which they put forward their best efforts and attained the success which had been recorded.

A comparison of the information regarding the geology of France and Palestine was also useful. The geology of northern France and the areas in which well-boring was carried out was well known before the war whereas the geology map of Palestine was an absolute blank in many districts. Dr. Hume, the geologist of Egypt, was only too glad to follow up the expedition as it proceeded, and glean what information he could from any possible source, and he was confident that Dr. Hume was able to obtain a very large amount of useful information from the records which had been so carefully and accurately kept by the author and Mr. Davson. That alone was a great achievement, because it would enable any future prospecting in Palestine, whether for oil, for water or for anything else, to be carried out in a much more confident spirit. The lesson to be derived from that was that if records were made of whatever work was carried out they became history.

Very few workshops were available in Palestine from which plant could be obtained. When Jaffa was abandoned by the Turks the plant in the German workshops there proved to be very useful. It was taken over very early after the occupation and turned to account, and a good deal of useful work was done with the machinery found, in connection not only with well-boring but with other work. The bulk of the plant, however, had to be obtained from Cairo, and it was exceedingly disheartening to feel that days and months had to pass before plant could be obtained or made. The railway was not always working—in fact, it did not always exist, just the same as water was not always available for use in well-boring. A great deal of it had to be transported on camels, and it was then necessary to have regard to every drop used.

To sum up, he thought the keynote of the paper was ingenious adaptation, great patience and dogged perseverance; the success which had been obtained was well deserved by the officers in whose

charge the operations were placed. It was a source of regret to him that the quiet work which was carried out by individuals and small parties would never be fully known and could never be adequately recompensed in a public manner. Everyone could not attain success, but they could at least deserve it, and, although the public might not know much about it, the satisfaction of having done one's job properly was a far better recompense than any other reward.

Mr. H. May said that Mr. Beeby Thompson had been asked to join in the discussion and relate some of his interesting experiences in Salonica, but unfortunately he was unable to be present owing to absence abroad. He would, however, like personally to mention one or two points in that connection, as he was associated with the work. The Star machine seemed to have given little satisfaction in Palestine, whereas several of that type of machine were used in Salonica with which about 130 wells were drilled to depths down to 600 ft. No. 22 Star rigs were used, and no serious trouble was experienced in spite of the fact that all kinds of sand and sandstone were successfully negotiated, necessitating the use of casing. He was inclined to think that the failure of that particular machine in Palestine was probably due to the fact that the operators were not experienced men. In Salonica they were in the enviable position of being able to engage their own men, and naturally selected the very best it was possible to find with long experience of that particular type of machine. It would be of great interest if the author could give further information with regard to the Fauck system, which he stated was so successfully used in Palestine. Many years ago, when drilling on an island in the Caspian Sea, he had to deal with some very difficult running sands, and he found that with the Fauck system, by using the return flush, he was able to cope with and overcome all the difficulties experienced. He would be interested to know whether that method was attempted with the Fauck rigs employed in Palestine. He would also be interested to know whether any of the sand screens of the type which was manufactured in this country after very great difficulty caused by the lack of detailed knowledge of the method of manufacture, consisting of a perforated tube upon which was wound a special wedge-shaped wire giving an aperture of anything from ·006 upwards, were employed. A number of that type of screen was sent to Egypt, and he would be interested to know if they were used in Palestine and whether they were successful.

Mr. A. W. Davson, in reply, said he had no doubt that Captain Mangin, when replying to the discussion, would give Mr. May the details he required of the Fauck system. Personally he was not a

mechanical engineer and did not profess to be able to deal with the mechanical side of the question, and he would therefore rather leave it to Captain Mangin to give the particulars asked for. Mr. May had also asked a question with regard to the sand screens and the tubes that were used. The only tubes they had during the period they were working consisted first of all of the galvanised slotted sand screen which they themselves covered with wire gauze. Ten days before he left Palestine, which was about three months after the Armistice, the Ashford patent sand screen, which he presumed was the one to which Mr. May referred and which was certainly the best screen they had seen in Palestine, arrived on the spot.

The Chairman said he was sure the members desired to convey their thanks to the author and Mr. Davson for the very interesting paper which had been presented. As Col. Paul stated, it very frequently happened that the men who did the most valuable work in out-of-the-way corners of the world received very little recognition. It was some tribute to Captain Mangin and his co-workers to find that their work was recognised at any rate at the Institution, that the members realised the difficulties that had to be overcome and the way in which they overcame them. It was rather a peculiar fact that even of old in the German universities the professors always preferred to have English assistants, because they said they were more practical. If they could not get the thing that was required they made shift to use something else. That was a characteristic of Englishmen, and it had been admirably demonstrated in the persons of the author and Mr. Davson. He was sure the members would desire to accord a most hearty vote of thanks to the author and Mr. Davson for their contribution.

The Resolution of Thanks was carried by acclamation.

Dr. Hume writes:—

I have received a copy of the interesting paper on "Boring in Palestine," presented by Captain Mangin to the Institution of Petroleum Technologists, with a request for me to contribute some remarks to the discussion.

It was my privilege to study the water operations from their first inception on the Suez Canal to the time when there was the long wait along the line at Gaza. It may be of interest broadly to state the conclusions arrived at in the course of the advance, these forming the basis of subsequent operations.

In 1915 the line of defence was on the Suez Canal and the military authorities felt the need of water supply for the troops occupying the desert side of the canal. The writer did not expect much success from boring operations undertaken here, as these were mainly sunk

in the lagoon or lake formations connected with the Mediterranean and Red Sea respectively. His only hope was that water filtering through from the run-off of the Sinai Hills might improve the brackish water supply. The tests proved that no such help was afforded and all the bores were abandoned.

As dunes are notably good water-collectors, he then suggested that boring operations should be conducted in the dune region some little distance east of the canal, and personally selected a position in front of the line at Katib el Aruq. Here the results proved more favourable, and the water was sufficiently good for animals, and just drinkable by men. So far as the writer knows, this plan was widely developed, and enabled the line to be maintained some distance inland of the canal itself. In this sand-dune water the salt was about 2500 parts per million.

A suggestion was also made to endeavour to tap the gravels of the ancient Nile arms which passed Pelusium, and to this end a bore was sunk at Mihemdiya in close proximity to a sand-dune region, but the water obtained was practically sea-water.

In the course of the investigation the interesting point came out that in the sand-dune areas there seemed to be a layer of fresher water resting on a more salty one at sea-level.

In the original reports made by the writer to the military authorities it was stated that the most noticeable feature proved was the existence of a water-table of wide extent at or near sea-level. Bir Mahadat, Bir Abu Aruq (Bir means well) proved to be all in this position. The water-table where it reaches the sea border is represented either by marsh, gypsum swamp, or palm grove depressions (as at Romani, Qatia, etc.). It was broadly concluded that along the Mediterranean border water of some sort could be met anywhere at zero level. Thus if any point were, let us say, 100 ft. above sea-level, the depth of the well required to reach water would be about 100 ft. As regarded quality, the nearer the water was to the lagoons or sea border, the greater its salt content. One could, in fact, divide the underground water into zones of diminishing saltness, which were more or less parallel to the borders of the great lakes (Menzala and Bardawil). The quantity of water was small at any one spot, but by tapping it at many localities, a large army was maintained on the Roani line many miles to the west of the canal over a considerable period.

The next study of importance was in connection with the El Arish area which the writer was invited by the military authorities to visit within a week of its occupation. Here it was evident that the rainfall absorbed by the sand-dunes and that flowing from the hills by the

great drainage line of Wadi-el-Arish had given rise to a most favourable area of water-supply, the best water, as in the previous case, being tapped when sea-level was attained.

It was calculated that the rainfall absorbed by the dunes would, if tapped by borings near their base, supply some 120,000 gallons per day. A total of 300,000 gallons per day was required for the troops on the spot, and this was obtained by boring to the east of the Wadi-el-Arish, and in the bed of that valley.

A notable feature was the excellence of the water close to the sea coast. This is true for the sand-dune area bordering the sea in the Nile Delta, and also for a similar region west of Alexandria.

Broadly speaking, such good supplies may be expected where a great drainage line carrying fresh water descends from the hills, especially if at the same time there is a water-collecting sand-dune area near the shore to strengthen the supply.

The importance of these shallow bore operations will be realised when it is remembered that nearly 150,000 men and 100,000 animals (horses, mules, camels) were maintained at this spot throughout a long period.

During the French expedition, Reynier's far smaller army found itself in a difficult position owing to the exhaustion of the existing wells, and was totally ignorant of the excellent supplies which lay close to the surface. The Germans and Turks seem to have been ignorant of the rich store of water thus available, and it will always stand to the credit of the Egyptian Expeditionary Force that it worked its advance on a basis of continuous study with striking results.

From this point the boring operations described in Captain Mangin's paper indicate the actual nature of the further work undertaken. The writer had, however, again the privilege of being invited to examine and report on the question of water supply for the Ghuzze line held by the Army to the west of Gaza.

Here the rules already laid down applied to the obtaining of the water from the sand-dunes, on which the left wing of the British Army largely depended.

As regards the centre and right wings, a new and important fact came into play. An examination of the springs at Shellal, Essani, etc., proved that the second great source of water-supply for the Gaza front was found in the valley deposits, the water being carried in gravels derived from the erosion of the limestone hills to east and south-east. This water was protected from evaporation and diffusion by overlying and underlying clays. As those camped in these parts learnt by sad experience, the quality of the water was less good than that of the consolidated dunes, and the gallant men on this portion

of the line had to drink water which under ordinary circumstances would be regarded as unsuitable for human consumption. Nevertheless these limestone-derived waters played a most important part in enabling the British Army to maintain its grip until the decisive advance took place. To the writer's deep regret he was unable to accept further invitations owing to the development of the policy of Petroleum Research by the Egyptian Government, and it has therefore been a source of great satisfaction to him to know that Captain Mangin is publishing the results of the boring operations undertaken. It must also be a great satisfaction to him and to Mr. Davson to know that their arduous labours were of such use to the effort which was led through such appalling difficulties to a triumphant conclusion by the labours, first of Sir Archibald Murray, and then of Viscount Allenby, assisted by the many able coadjutators with whom the writer was privileged to work. He would desire very specially to thank Sir Philip Chetwode, to whom his reports in the field were mainly presented.

Captain Mangin writes as follows:—

The official notes of the discussion on my paper on "Boring in Palestine," read by Mr. A. W. Davson on the 14th ultimo, have just reached me.

In reply to Mr. May's remarks with regard to my criticisms of the "Star" rig, I am somewhat at a disadvantage in that I have no copy of the paper with me at the moment, but I recollect the statements to which no doubt Mr. May refers, and must admit that, as they stand, they require some explanation, or rather amplification.

In the class of geological formation for which it is suitable, the "Star" machine is probably faster than any other "portable" rig on the market; that is to say, the drilling gear, as distinct from the hoisting gear, is excellent. Under the conditions obtaining in Palestine, however, the efficiency of the former is comparatively unimportant, while success or failure depends upon, firstly, a properly designed draw-works, and, secondly, ease of control. These two latter factors are, in my opinion, the weak points in the "Star" design.

In the very unstable formations met with, the whole problem of drilling resolves itself into one of handling casing, and the "Star" rig is provided with no casing spool, and no other spool which can, without considerable strengthening, be safely used for handling a heavy string through difficult sands.

As regards ease of control no "single lever" control with a neutral, central position, such as that utilised on this machine, can be considered adequate to deal with heavy loads under the conditions obtaining in the class of formation under discussion.

The net result of these deficiencies is that the casing has to be committed to its fate at an early period in the operations, and coerced by various methods—including the most pernicious of all, viz. driving—to follow the tools or sand-pump as the bore proceeds.

Under these conditions it is very largely a matter of luck as to whether the bore is completed with the first, second, or third string of casing, and, in cases where the operator is tied to a certain size of pump and tubing, chances of this nature cannot—or should not—be taken. When provided with efficient hoisting gear, the driller should be able to maintain his casing under control through very considerable thicknesses of loose and running sands, but if he has to change his lines, as in the case of the "Star," before he can move his casing, there are many conditions under which the latter would become too tight to respond to anything but the jacks.

With regard to the conditions in Salonica, I can speak only with second-hand knowledge, but one of Mr. Beeby Thompson's drillers, with whom I compared notes in Cairo, admitted that he had met with no conditions in that part of the world to compare with those in Palestine for difficulty. Having said so much, however, it is only fair to state that, on the average, the rate of progress with the "Star" and the other types was about the same, owing to the very excellent performance of the former whenever there was any real drilling to be done, but the worry and anxiety, not to mention the amount of manual labour, was often excessive, and the continual uncertainty of results extremely trying.

Under the circumstances I do not think that fully experienced personnel could have shown much improvement in the results obtained: our men, though admittedly lacking in the wide experience of the professional driller, had been very carefully taught and trained for the conditions under which they were working, and, within these limits, were remarkably efficient.

To turn to the question of the Fauck rig.

Mud-laden fluid systems are in use in America where the geological surface conditions are similar to those existing in Palestine. I believe also that they are now finding favour in certain fields in Europe. I was, however, very interested to hear that Mr. May had obtained such good results with this particular type of plant as, for some unexplained reason, the majority of engineers with whom I have discussed it either have no experience with the rig or dismiss it in a few words as being of no particular interest.

I hesitate to do more than barely touch on the question here.

The keynote of successful operation appears to me, from experience

gained in Palestine and elsewhere, to be the proper control, first, of the consistency of the slurry, and, secondly, the pressure under which it is applied, which again controls the velocity of flow through the bore. A common trouble was the excessive deposition of mud on the walls of the bore or near the surface, but I am satisfied that this was due to improper means of control of the two factors mentioned above.

The removal of surplus clay from the bore after completion presents some quite interesting problems, and it was often found that an apparently clean hole had filled up with mud, after the insertion of casing.

It should be noted that the consistency of the "slurry" needs to be continually varied according to the nature of the formations being penetrated, and this again presents peculiar difficulties, as it is often impossible to know to what extent the consistency may be reduced without producing caving.

In conclusion, I wish to express my thanks to Col. Paul for not only his very generous support on this occasion, but, in conjunction with Mr. Davson, for the encouragement and support extended to us through a period of nearly two years on the Palestine Front, when the very existence of the Boring Section, as such, depended upon the good offices of a few senior officers who appreciated our efforts.

In the absence of the author, the following paper was read by Dr. Dunstan :—

Estimation of Sulphur by the Lamp Method.

By F. Esling, A.C.G.I., A.I.C., *Member*.

1. The method for which this apparatus was devised is to burn a weighed or weighable quantity of the oil either *per se* or in solution in a sulphur free solvent, absorbing the products of combustion in a measured volume of standard sodium carbonate solution which is finally titrated with a standard sulphuric acid solution. Like most rapid methods this one is not attended with absolute mathematical precision; at the same time, the experienced and careful operator can obtain figures reliable to a few units in the third place of decimals in percentage. All methods of sulphur estimation undoubtedly have their disadvantages, but I believe that in this instance they are more apparent than real, particularly when the apparatus is in the hands of a trained chemist.

2. The apparatus consists of :—

(1) A small lamp made entirely of glass, which is small and light for the purpose of weighing; the centre tube of the lamp which carries the wick should have an internal diameter of 3 mm. and should reach almost to the bottom of the container, the capacity of which is approximately 10 cc. The side arm attached to the body of the lamp is for the purpose of adding small quantities of solvent. The stopper is provided with a small nick to keep the interior of the lamp always at atmospheric pressure. The wick used is ordinary cotton wick as sold by chemical apparatus merchants for use in spirit lamps; a sufficient number of strands should be employed so as to fill the centre tube comfortably, being neither too loose nor too tight.

(2) A pair of bulbs of the U-tube type, with an anti-splash bulb at the top of one of them; the shorter bulb is left empty and acts as a partial condenser for the products of combustion; the second and longer of the two absorption bulbs is packed fairly closely with well-washed glass wool. It is necessary to make a particular point of the washing of the glass wool. In my earlier experiments in this direction, carried out in 1912, I used small glass beads; these served the purpose well for the class of oil I was working with at the time, which contained 0·2 to 0·8% sulphur; but later, on a different class of petroleum

distillates with one-tenth the quantity of sulphur, it was found desirable to increase the absorption surface as much as possible, hence the use of glass-wool.

My first attempts with glass wool resulted in chaos, owing, I found, to the wool being strongly alkaline (a very persistent property even after many washings); this led me to wash my glass-wool very thoroughly with acid and water until neutral. I used strong nitric acid and boiled well; but this is probably unnecessary—dilute acid may do equally as well. I imagined I had encountered a particularly bad sample, and consequently made no point of its alkalinity; however, both Mr. Guthrie, in Egypt, and Mr. Brewster, in Persia, have since experienced the same trouble and have communicated to me their difficulties in endeavouring to obtain neutral wool. The rest of the apparatus consists of:—

(3) A small glass chimney beneath which the lamp is placed;

(4) A suitable stand; and

(5) A filter-pump or other convenient apparatus for aspiration.

3. *Process applied to Lamp Oils.*

The simplest class of oil that can be burnt in an apparatus of this type, is obviously an oil that will burn by itself with a clear flame; such an oil as lamp oil, kerosene, or paraffin oil. In such cases the method is to fill a small quantity of the oil into the lamp and weigh it; the apparatus being fitted up and 20 ccs. of a sixteenth normal solution of Na_2CO_3 added to the absorption bulbs, the pump is started and the lamp lighted and placed beneath the chimney. The draught should be regulated so as to maintain a clear non-smoky flame—a fairly rapid draught is usually required. Tendency to smoking may be due to the wick of the lamp being too high and requiring adjusting. It is always advisable to adjust the wick and get it set to a small clear flame previous to taking the first weighing. From half an hour to one hour will be found sufficient time for a burning; in that time from 0·5 to 1·2 gram. of oil will be burnt. It now remains to extinguish the lamp and reweigh it to determine the quantity of oil burnt. The absorption bulbs, anti-splash bulb, and chimney should all be carefully washed out into a flask, taking care to wash the bulbs well, blowing out as dry as possible after each washing with distilled water. Using methyl orange as indicator, the titration with sixteenth normal H_2SO_4 is performed to a predetermined end-point. Sixteenth normal solutions are used to simplify the calculation, as will be seen later. The predetermined end-point for the titration is arrived at in the

periodic checking of standard solutions. 20 cc. of the standard sodium carbonate solution are introduced into a flask, using the same pipette or burette as is used for the experimental work; this is diluted with distilled water to about 200 cc. volume, which is approximately

the volume arrived at after washing out the absorption bulbs, etc., and a sufficient number of drops of a dilute methyl orange solution added (the actual number of drops should always be noted). The standard acid is now run in until the operator arrives at the tint desired; preferably a happy medium between the yellow and pink colours. The reading given by the standard acid burette is taken as

the true strength of the soda solution. It is immaterial whether this is 19·9 or 20·1 cc. This flask, with contents tinted to the desired colour, is securely corked and used as *End-Point* standard. It should not be kept longer than a week or ten days. Now, after performing a test, if the bulbs be washed out into a similar flask, the volume being approximately the same, and the same number of drops of the same strength methyl orange solution added, the titration may be carried out to the same final colour tint; and the difference between the volume of the acid used in the test and that used in arriving at the standard colour gives a direct determination of the amount of sulphur in the oil burnt.

The calculation is extremely simple :—

If V_1 = vol. of $N/_{10}$ acid equivalent to 20 cc. standard soda, and
V_2 = vol. of $N/_{10}$ acid used to neutralize after burning test,
and W = weight of oil burnt, then :—

Percentage of sulphur in sample is given by :—

$$S = \frac{(V_1 - V_2) \times 0{\cdot}001 \times 100\%}{W}$$

the factor 0·001 being the equivalent in terms of sulphur of *one* cc. of $N/_{10}$ solution.

As a works test for the control of kerosene refining, I have found this method extremely useful and accurate; it being possible to arrive at a result within an hour of the receipt of the sample from the washers.

4. *Highly Volatile Oils (Oils of very low Flash Point).*

The method was originally devised for the testing of lamp oils, but I have been able, by the use of various solvents, to extend it to other types of petroleum oils, the main difference being that a predetermined weight of oil is burnt, using a sufficient quantity of solvent for the purpose. In the case of petrol, benzol, and substances of like nature, with a very low flash point, it is found not possible to burn these direct owing to the excessive tendency to smoking which cannot be controlled. The usual procedure in such cases is to dilute the spirit with absolute alcohol. It might be added here that in hot climates the absolute alcohol could conveniently be replaced by a higher boiling solvent, such as amyl alcohol or amyl acetate, or by a mixture of amyl and ethyl alcohols, which would tend to give a more readily controlled flame. In temperate climates a 20% solution of petrol in alcohol gives a clear burning mixture. A definite measured volume of the alcohol-spirit mixture is burnt.

A standardized 5 cc. pipette is used to introduce a known quantity of spirit into a standardized 25 cc. flask which is filled to the mark with alcohol (or other solvent). The specific gravity of the spirit is taken at the moment of removing the 5 cc. sample; the product Vol. × Sp. Gr. giving the actual weight of oil taken. A 10 cc. quantity of the alcohol-spirit is transferred by means of a standardized pipette to a lamp, the wick of which has already been adjusted for burning [duplicates can be run side by side on the same mixture]. The lamp is burnt, as in the case of lamp oils, with the clearest obtainable flame (avoiding smoking) until the flame is nearly extinguished; the side stopper is removed and about 1·0 to 2·0 cc. of alcohol introduced by the side arm; the lamp is again allowed to burn to dryness and a further small quantity of solvent added, which is again burnt to dryness as before. With two washings out in this manner the lamp is taken to be sufficiently free from motor spirit for all practical purposes. The washing out of the bulbs, chimney, etc., and the titration to neutral tint are carried out as indicated above, with the exception that in this case I use $N/_{23}$ sulphuric acid in place of the $N/_{10}$ solution.

The calculation is slightly more complicated:—

Let D = Sp. Gr. of motor spirit at temperature of drawing sample;

a = Actual capacity of the 5 cc. pipette used;

b = „ „ „ 25 cc. flask used;

c = „ „ „ 10 cc. pipette used;

then *W*, the weight of spirit actually burnt in test, is given by

$$W = D \times \frac{a \times c}{b}$$

It will be seen that if the same pipettes and flask are always used, the quantity $\frac{a \times c}{b}$, being the actual undiluted volume of spirit burnt, remains the same for all tests. With W determined, the calculation as given above for lamp oils can be applied.

It is always advisable to run a blank test on the alcohol, using as nearly as possible the same amount as is used in a test; this, of course, need only be done once on any supply of alcohol.

In the course of a number of blank estimations I have never yet had to apply a correction factor on this account.

The time for the completion of a test on motor spirit is approximately *three* hours. It is unnecessary to remark that the atmosphere of the laboratory should be uncontaminated with acid fumes, ammonia, H_2S or SO_2, etc., since a large volume of air gets drawn through the bulbs during the course of a three-hour test.

5. *High Flash Point Oils (Refined Gas Oils, Light Lubricating Oils, etc.).*

For oils of this type (and all other oils of low volatility and poor capillarity) it is generally possible to weigh directly into the lamp from a small beaker, or to use a Lunge-Rey pipette. According to the class of oil and its possible sulphur content, the operator can best determine for himself whether 0·2 or 1·0 gramme should be taken for a test. With an oil of moderate sulphur content I have used 0·25 gramme with quite satisfactory results.

A mixture of ethyl and amyl alcohols, or amyl alcohol itself, may be used to assist the combustion of oils such as gas oil, intermediate oil, jute batching oils, and even thin paraffin-free lubricating oils. For heavier oils, such as cylinder oil, heavy lubricating oils, greases of a petroleum jelly nature, distillate fuel oils of shale oil type, and some crude oils which are free from asphaltic bodies; it has been found preferable to use amyl acetate as a solvent. Having weighed out the required amount of oil, either directly or from a Lunge-Rey pipette, 5 to 6 cc. of the solvent are added to get the oil into solution and the lamp is burnt in the usual way, adding two or three small quantities of solvent to complete combustion of the oil. Generally speaking, owing to the lower volatility of the solvents employed and the still lower volatility of the oil itself, the actual combustion of oils of this class takes anything from 3 to 4½ hours. Again, it is necessary to run blank determinations on the solvent. The author would like to make it quite clear that, although the method and apparatus he puts forward here may be used with a very fair degree of accuracy for determination of sulphur in oils of these classes, the bomb method must still take precedence in cases where extreme accuracy is of first importance. For the other classes of oils dealt with above, this remark does not apply.

Effect of Asphalt

It will be observed that I have dealt particularly with oils free from asphalt and asphaltic matter. Asphalt, no matter how small the quantity and how well dissolved, is apparently outside the possibilities of a small lamp. Many crude distillates, such as unrefined gas oil and shale oil, contain a small quantity of asphaltic or pitch-like substances which tend to clog the wick of the lamp and are left behind, together with a large portion of the sulphur present in the oil, after the burning test is completed.

To illustrate the effect produced on the ultimate result, either volu-

etric or gravimetric, I will give the results obtained on two unrefined as oil distillates :—

Gas Oil from a Mexican Crude Oil.

(1) Sulphur by lamp—Volumetric ..(*a*) 1·55 %
(*b*) 1·57 %
(2) „ „ Gravimetric .. 1·71 %

Sulphur found in the lamp wick after use :—

(*a*) —0·12 % (*b*) —0·117 %

(3) Sulphur by Mahler bomb .. .. 2·11%

Gas Oil from an American Crude Oil.

(1) Sulphur by lamp—Volumetric ..(*a*) 1·735%
(*b*) 1·745%
(2) „ „ Gravimetric .. 1·70%

Sulphur found present in wick after use :—

(*a*) 0·182% (*b*) —0·196%

(3) Sulphur by Mahler bomb .. .. 2·20%

By adding the sulphur still remaining in the wick to the results obtained volumetrically or gravimetrically, the resulting figures approximate more closely to the bomb result, but are still lower than these ; e.g.

A. gives Vol. 1·68 % B. gives Vol. 1·93 %
„ Grav. 1·83 % „ Grav. 1·89 %
„ Bomb 2·11 % „ Bomb 2·20 %

A crude oil which gave 1·15% sulphur by bomb, only showed 0·57% by lamp method volumetrically ; it contained between 3 and 4% of non-volatile asphaltic substances. It is therefore necessary to give expression to this warning—namely, that, excepting petrol and kerosene, the lamp method is only applicable to refined petroleum products free from asphaltic matter ; and is even then not recommended where a bomb calorimeter is available.

6. *Typical Results.*

KEROSENE.—The following results were obtained by a junior assistant :—

Sample.	*Test* 1.	*Test* 2.	*Test* 3.	*Test* 4.	*Mean.*
A	0·151 %	0·156 %	0·166%	0·160 %	0·158 %
B	0·104 %	0·111 %	0·100%	0·101 %	0·104 %
C	0·076 %	0·065 %	0·071%	—	0·071 %

Sample.	*Test* 1.	*Test* 2.	*Test* 3.	*Test* 4.	*Mean.*
D	0·064 %	0·070 %	0·071%	0·073 %	0·070 %
E	0·088 %	0·091 %	0·086%	0·084 %	0·087 %
F	0·054 %	0·059 %	—	—	0·057 %
G	0·074 %	0·076 %	—	—	0·075 %
H	0·091 %	0·0908 %	0·0951%	0·0987 %	0·0921%

It is interesting to observe the gradual increase in accuracy that the operator attained with continued practice.

PETROL.—In the case of petrol testing, the time taken was usually about three hours. It was therefore essential to make careful blank tests with the object in view of not only checking the alcohol, but more particularly the influence of possible acid contamination in the air. The question arose as to whether the sulphur present in the oil was all converted to sulphuric acid, or part was left in the less oxidized state of sulphur dioxide; and if so, how would this affect the final titration. A further doubt also arose as to whether organic acids might be produced during a combustion and materially affect the result. The first doubt relating to atmospheric contamination was allayed by the blank tests showing no result at any time; care was naturally taken to keep the air of the laboratory as free as possible from contamination. In the question of complete or partial oxidation it is doubtful if such a case as partial oxidation would materially affect the end-point tint, which is supported by the fact that gravimetric results obtained by the usual process of oxidation with bromine and precipitation as barium sulphate, have shown very little difference from the volumetric results, a fact which *also* goes to show that any fears that organic acids might be produced in quantity sufficient to cause a noticeable error were unsubstantiated.

In the following figures, picked at random among many results carried out by a laboratory assistant, I have endeavoured to show a comparison between the volumetric method suggested and determinations made by a final gravimetric precipitation process :—

	Volumetric Determinations.					Gravimetric
Sample.	*Test* 1.	*Test* 2.	*Test* 3.	*Test* 4.	*Mean.*	*Tests* 1, 2.
A	0·071 %	0·074%	0·078 %	—	0·074 %	0·076/1 %
B	0·037 %	0·034 %	0·037 %	—	0·036 %	0·0334/1 %
C	0·1107 %	0·1127 %	0·1120 %	0·1070 %	0·1106%	—
D	0·0463 %	0·0476 %	—	—	0·047 %	—
E	0·3020 %	0·3000 %	0·3018 %	—	0·3013 %	—
F	0·0702 %	0·0718 %	0·0735 %	—	0·0718 %	0·0737/1 % 0·0737/1 %
G	0·0280 %	0·0289 %	0·0252 %	0·0271 %	0·0275 %	0·0291/1 % 0·0272/1 %

An examination of these figures will reveal the fact that for all general purposes the volumetric estimation is quite near enough to a gravimetric result, obtained after a similar burning test by the usual precipitation process. The recording of results to the fourth place of decimals is not done with the intention of suggesting that this is or should be general practice, the second significant figure is usually quite sufficient for all practical working.

7. Limits of Accuracy.

In an analytical process involving both weighing on a balance and volumetric measurements by pipette and burette, one is often led to make use, with absurd accuracy, of the third and fourth place of decimals in weighing, without consideration of the extent of accuracy possible with the burette.

If it be assumed that the 20 cc. pipette used for measuring the standard N/16 sodium carbonate solution is accurate, making use of set rules for delivery, such as allowing it to drain for 15 secs., touching the side of the receiving vessel or the surface of the liquid to take off the last drop, etc. etc., an accuracy of greater than $\pm$ 0·02 cc. cannot be expected.

In reading the burette, which may be one divided into 1/20ths of a cc., and imagining the divisions to be accurate, the nearest possible reading is to half a division, i.e. 0·025 cc., which involves a further error of $\pm$ 0·025 cc.

The total maximum error in these two cases is therefore $\pm$0·045 cc., which on N/16 solutions is equivalent to $\pm$0·000045 grs. sulphur; and in percentage, considering one gramme of oil to be burnt, this means a possible error for the operations of measuring of $\pm$0·0045% without taking into account the various operations of washing out the bulbs, and matching the colour tint.

It is obvious that for an oil containing 0·1 % sulphur—and many contain less—0·01 gram. would contain 0·00001 gram. of sulphur, and it is hardly necessary to weigh the sample to a greater degree of accuracy than the second place of decimals, since an error of *one* in the second place would only mean an error of 0·001% (assuming one gramme of oil to be burnt). On the other hand, in the case of an oil containing 3·0 % of sulphur, and the quantity burnt in a test is 0·25 gram., the same error in weighing would create an error in the final result of 0·12 %; consequently, as a general rule, I have made a practice of weighing to the third place in all cases, thereby making my maximum error $\pm$0·0005 gram., which in the extreme case given above makes a possible error of $\pm$0·006 %, which is only 2 in 1000 on an oil with a sulphur content of 3·0 %.

In the case of the eight kerosenes, the results of which are tabulated above, I have applied the principle of "Mean Squared Error" to obtain the degree of possible error over the whole operation. It should be remarked that the quantity burnt averaged between 0·8 and 1 gramme, and from the results it will be observed that the sulphur content approximated 0·09 %; by taking means and squaring the difference between each result and the corresponding mean, the following figures for the average mean-squared-error for each sample were obtained:—

Sample A	30×10^{-6}	for 4 determinations.	
„ B	$16{\cdot}5 \times 10^{-6}$	„ 4	„
„ C	20×10^{-6}	„ 3	„
„ D	$11{\cdot}5 \times 10^{-6}$	„ 4	„
„ E	$6{\cdot}8 \times 10^{-6}$	„ 4	„
„ F	$6{\cdot}5 \times 10^{-6}$	„ 2	„
„ G	$1{\cdot}0 \times 10^{-6}$	„ 2	„
„ H	$2{\cdot}8 \times 10^{-6}$	„ 4	„

The mean of these twenty-seven results is:—

MEAN ..... $11{\cdot}9 \times 10^{-6}$;

and the square root of this is—

$\pm 0{\cdot}00345$,

showing that the probable error on sulphur determinations on kerosenes is of the order $\pm 0{\cdot}0035$ %; a figure which is somewhat less than the maximum estimated error shown above for pipette and burette readings in these tests; i.e. $\pm 0{\cdot}0045$ %.

In *Motor Spirit* testing it is generally found that the pipettes used for measuring out the motor-spirit and the alcohol-spirit mixture will deliver to a greater accuracy than when delivering water solutions; and with these apparatus, in conjunction with a hydrometer reading to the third place of decimals, it has been estimated that the possible error does not exceed 0·01 grms. of the actual undiluted spirit. The quantity burnt in a test amounts to 1·4 to 1·5 grms. An effort to minimize the error of burette reading is attempted by using a N/32 solution of acid for the final titration; but a good light and a well-practised eye are essential in order to distinguish the difference in tint made in 200 cc. of solution by half a drop of N/32 acid; nevertheless, this is not asking for the impossible, as will be seen by comparing the volumetric and gravimetric figures given above for motor spirit. It stands to reason that, with the same attention to details as suggested, the greater the quantity of material burnt the less the proportional error.

Other Workers, their Methods and Suggestions.

It was remarked recently in a discussion on the testing of motor fuels that "the estimation of sulphur by burning was as old as the hills"; this is obviously true—the novel method would undoubtedly be that *not* involving combustion.

The CARIUS method still remains unquestionably the accurate method; its general use in works-laboratories is just as unquestionable.

The REFEREE test for gases, and the modified form for benzols, still enjoys fairly extensive use; it cannot be called rapid.

The BOMB CALORIMETER, as originally devised by Berthelot, modified to a cheap form by MAHLER, and still further modified by other workers, such as Cook and Krocker, is used to a considerable extent in the Petroleum trade. However, its use for the determination of sulphur in very volatile oils is always attended with grave doubts owing to the unavoidable losses due to evaporation of the light substances. For oils of low volatility it gives almost everything desired except rapidity.

LAMP METHODS applied to motor fuels have been fairly extensively adopted, the majority of the methods being completed by gravimetric determination of the sulphur as barium sulphate; the solution used as absorbent for the products of combustion, however, shows greater variety.

Among those involving a final *gravimetric* determination may be mentioned the methods of Allen, Heusler, Engler, Kissling, Fischer, Friedlander, and Maturin; in all of which the products of combustion are absorbed in dilute sodium or potassium hydroxide, the oxidation made certain with bromine water, and barium chloride used for precipitation.

Sanders absorbs his gases in a solution of sodium peroxide, and precipitates with barium chloride in the usual manner. His lamp is constructed from a platinum crucible, which he finally heats to a red heat in order to drive off the last traces of spirit.

Hewitt, who found it difficult to oxidize the thiophenic-sulphur present in benzols by the simple process of burning, passes the vapours through a red-hot silica tube; he absorbs in caustic soda solution, oxidizes with bromine or hydrogen peroxide, and precipitates as barium sulphate.

Dunstan and *Thole* burn a solution of the oil in three volumes of alcohol in a small lamp (a little amyl acetate being added, if necessary) and aspirate the products of combustion through sodium carbonate. Before precipitation, sodium peroxide is added to the solution to ensure oxidation of any sulphite (Jour. Inst. Petr. Tech., 1917, iv, 33).

Among the processes involving a final *volumetric* determination th following are worthy of mention :—

Burton absorbs in normal sulphuric acid and titrates with norm sodium carbonate. He uses oo-tropaoline as indicator.

Schultz uses a neutral solution of hydrogen peroxide as absorb and titrates with N/10 alkali, using methyl orange.

Schenk firstly volatilizes his spirit in a current of air, and burns th gas in a specially constructed vessel, absorbing the sulphuric ac formed in hydrogen peroxide.

Bradbury and *Owen* also use a special carburetter and burn thes gases in a bunsen burner, in the flame of which is placed a small coi of platinum wire which ensures complete combustion of the sulphu The sulphuric acid is estimated volumetrically.

Conradson was first to point out that sulphonates and sulphates being non-volatile, would be left in the wick of the lamp (the bom method would give total sulphur in whatever form it was present). Conradson suggests methods for the combined and separate determina tion of this non-volatile sulphur by oxidation of the wick and grav metric determination. It need hardly be remarked that in a properly refined motor fuel or any other petroleum product no sulphates o sulphonates should be present, but a simple method of determining them when they are there is certainly useful. Conradson's method wa made use of in the determination of sulphur in the lamp wick after the combustion of the two gas oils, the results of which are shown on page 89; in this case the sulphur retained by the wick was asphaltic sulphur.

DISCUSSION.

The Chairman said the author had made an admirable contributio to a subject which was brought before the previous meeting of the Institution, when a fairly good discussion occurred on other aspects of the same matter. He hoped a good discussion would now ensue, because it was quite obvious that the whole of industry was vastly helped if accurate methods could be obtained for determining any ingredient, particularly if those methods were at the same time capable of being carried out rapidly. To his own knowledge, the whole question of running plant in other industries depended upon the rapidity and accuracy with which analyses could be made. It was no use doing an analysis that took four or five hours, during which time the plant might have done four hundred or five hundred pounds worth of damage, so that the members would appreciate that the subject under discussion was a really valuable one.

Dr. Thole said he desired to make three comments on the paper

which might possibly be of assistance to others who used the method of analysis described. The principal difficulty he had experienced in using the author's type of apparatus, a difficulty which might have been met with by other people, was the strongly marked tendency there was for the lamp to smoke. He experienced a similar difficulty at first when using the lamp method, and found it could be to a very great degree obviated by using a chimney over the lamp of about six times the capacity which the author used, so that there was a larger air reservoir round the flame. The combustion of only a portion of the oil, which was the procedure the author used in burning kerosene, was, he thought, a risky one, because there was very probably a tendency for the wick to absorb some of the components of the oil selectively. For example, the sulphur compounds might be held to the wick more firmly than the non-sulphur compounds, and therefore the final result would naturally give too low a figure. He thought it was necessary to insist, in order to obtain real accuracy, on the taking of a definite quantity of oil and burning it right out completely, not simply burning a portion. The volumetric estimation of sulphur possessed the great advantage of speed, a fact the author emphasised in his paper, but what was gained in speed was, he thought, lost to a certain extent in accuracy. He had found in some other experience that the volumetric estimation always gave slightly higher results than the gravimetric estimation. In an endeavour to trace out the reason for that, he carried out the experiment of burning absolutely non-sulphurous petrol, and on testing the products of combustion he found they contained quite an appreciable amount of nitric acid. Apparently the heat of the flame was sufficient to cause a very small but quite perceptible amount of combination of the oxygen and nitrogen in the air, and the formation of such nitric acid gave rise to a slightly higher result.

Mr. H. V. Mitchell, in referring to the point raised in connection with the risk involved in using light oils such as petrol with the bomb-calorimeter, said he remembered a case in which a bomb was damaged in determining the calorific value of a sample of petrol in the laboratory of the late Sir Boverton Redwood. The sample of petrol was therefore sent to the laboratory of another analyst, with the result that a second bomb was completely wrecked beyond repair. There were other cases on record in which the same kind of thing had occurred. He did not think these occurrences should be altogether dismissed as being due to mishandling or using too large a quantity of the sample, because he knew of cases in which, with one gramme of petrol, bombs had been decidedly damaged, and in one case completely wrecked.

Mr. Lawson Lomax said he had carried out well over a thousand sulphur estimations by the bomb method and had experienced no trouble whatever. In certain circumstances, however, when unduly high oxygen pressures had been used, a slight noise occurred inside the bomb just at the time of firing, and it might appear as if a small explosion had occurred inside. That might be propagated through the bomb and do some damage, but he had never seen a bomb damaged except when unduly high oxygen pressures had been used. The instructions supplied with the bomb stated that 25 atmospheres were necessary for complete combustion of light oils, but personally he had found that 10 atmospheres were quite sufficient, and when using that pressure he had experienced no trouble whatever.

The Chairman said he was sorry that Mr. Moore had left the meeting, because he knew that gentleman had done many hundreds of estimations of sulphur in petrol, light oils, medium oils, and heavy oils, in a Cook bomb; and Mr. Moore was still with them, quite happy and doing his work daily, so far as he knew. With regard to the question of the utilisation of glass wool, glass wool was nearly always made from a very soft alkali-containing glass, and it was an abominable material to use. A very beautiful substitute, however, was obtained by using quartz glass, which was, however, somewhat expensive. Unless great care was taken the capillary tubes were also unfortunately generally made from a very soft glass, out of which an appreciable amount of alkali could also be taken. The utilisation of the lamp method turned, in his opinion, primarily on the question of the adsorption of sulphur compounds in the cotton or the substance of the wick employed. The improvement suggested at the last meeting of using quartz capillary tubes in a quartz tube tended to remove that difficulty, because quartz did not absorb those bodies to any very considerable extent. He had recently discovered how impossible it was to use ordinary glass vessels when endeavouring to do experiments connected with the colloidal state of clay, and he had come to the conclusion that the delicacy of clay in its behaviour under the present alkalis or acids was such that it was absolutely impossible to work with glass vessels of any description; it was necessary to work with quartz vessels.

The meeting then terminated.

The Fifty-second General Meeting of the Institution was held at the House of the Royal Society of Arts, John Street, Adelphi, W.C., on Tuesday evening, 18th January, 1921, Sir Frederick Black, K.C.B. (the President), occupying the Chair.

The Secretary read the list of new Members, Associate-Members, Students, and Associates elected on the 16th December, 1920, since the last meeting of the Institution, as follows :—

As *Members* :—William Travis Arnett, Lindon Wallace Bates, Henry Lowry Lambert Beresford, Cyril Nowill Bromehead, Paul de Chambrier, Joseph Alfred Chown, Herbert John Davies, Edward Dixon, Robert Bertram Grey (transference from Associate Member), William Groundwater, Jack Lane Jeffery, Frederick Lamplough, John Malcolm Muir, Haylett O'Neill, John Thomas Norman, William Francis Parish, Toyokiohi Takakuwa, George Turner.

As *Associate Members* :—Thomas Sutton Bowman, Paul Douet, Stanley Charles Frost, Walter Hill, Kenneth Charles Macgregor Mackenzie, Percy Frederick Thurlow, Launcelot Potter Timmins.

As *Students* :—Herbert George Austin, Major Harry Cecil Frank Drader, Robert William Langham, John Frederick Frank McQueen, George Sell.

As *Associates* :—Frank Travers Carlton, Anders Eric Knos Cull, Nathan Wesley Hale, George Ritchie Llewellyn, Hugh Micklem, Thomas Prates Norman, Graham Wallis.

The President said it had been expected that a paper would have been read at the present meeting upon "Oil Losses and their Elimination," by Mr. Beeby Thompson. Mr. Thompson was, however, away from the country on business, but the Institution was very fortunate in being able to substitute a paper by Mr. Garner on the results of work that he had done at the Mellon Institute of Industrial Research at the University of Pittsburg, U.S.A., on "The Carbonisation of Lubricating Oils in Internal-Combustion Engines." In the absence of the author, Dr. Ormandy was not only going to read the paper, but, like the bold man he was, he had volunteered to do his best to reply to the discussion. If any special points were raised which necessitated a reference to Mr. Garner, Dr. Ormandy would communicate them to Mr. Garner and get his opinion on the subject.

The following paper was then read in precis by Dr. W. R. Ormandy :—

The Carbonisation of Lubricating Oils in Internal-Combustion Engines.

By Frederic H. Garner,

Mellon Institute of Industrial Research, University of Pittsburg, U.S.A.

I.

Introduction.

In the lubrication of internal-combustion engines the character of the oil used is determined mainly by the high temperatures produced in the cylinders by the combustion of the fuel; it is essential that no decomposition of the oil shall occur which may interfere with the smooth and efficient operation of the engine. Minimum carbonisation of the oil must therefore result in the cylinders and, on the other hand, the oil must reduce friction as far as possible and remain in effective service for a long time.

The translation of such requirements into definite properties which can be ascertained by laboratory tests has not proved simple as there are many factors which influence and determine the behaviour of a lubricating oil under such severe conditions. Small quantities of impurities in the oil affect the quality of the lubrication produced to an extent quite unexpected from the proportions present.

It is of fundamental importance to correlate laboratory tests of lubricating oils with those obtained by actual engine tests; many difficulties arise in carrying out such tests on a sufficiently large scale to determine definitely the relative merits of various oils, since apparently minor factors in the operation of the tests may exert much greater influence on the results than is produced by the change of lubricating oil. Consequently, the paper of W. F. Parish (152*) on the comprehensive tests carried out on aeroplane lubricating oils is an important addition to the scanty literature of this subject.

The nature of the oil used for lubrication will depend on certain features of the engine, such as the method of cooling, the speed of revolution, and the clearances of the engine, and accordingly oils of different physical properties are demanded for the varied types of engines. Certain qualities, however, should be possessed by all such oils to ensure that the engine will continue in serviceable operation without necessitating frequent overhauls on account of carbon deposits and excessive wear. It is on this account that tests other than those

* These references are to the bibliography. See Section IV.

ordinarily made on oils for the lubrication of machinery operating at ordinary temperatures are necessary to discriminate between various oils intended for the lubrication of internal-combustion engines.

The special laboratory tests used for this purpose are the determination of the evaporation loss and of asphaltic matter produced by exposing the oils to high temperatures and of the so-called coking value or carbon content of the oil.

These tests are also used in the examination of lubricants for air-compressors and steam engines and of transformer oils, since for these purposes the determination of the deterioration in the quality of the oil at high temperatures is of great importance.

The connection between evaporation loss, carbonisation, and coking value and other properties of lubricating oils is discussed in the following paragraphs.

Evaporation Loss.—The evaporation loss at various temperatures must be connected in a definite manner with the range of distillation of the oil as determined in a partial vacuum or by means of superheated steam; these properties of the oil and the flash point and fire test are all linked up with the vapour pressure of the oil at different temperatures. Other factors are also of importance, for the evaporation loss is dependent on the decomposition of the oil that occurs at high temperatures and on the content of non-volatile material, i.e. of asphaltic resins and asphaltenes.

The flash point of an oil (and fire test) are probably related to its initial boiling point, or at least to the distillation range of the initial fractions, since, as is well known with kerosene, the presence of a small amount of gasoline has an enormous effect on the flash point (47, 48, and 50). It would seem that the flash point, at least in the case of adjacent fractions of the same crude petroleum, depends on the temperature at which a definite vapour pressure is attained, and at this pressure the requisite concentration of vapour in air is formed to produce an explosive mixture. From Holde's figures (49) on the flash points of various naphtha fractions, it may be seen that in this instance the flash point is approximately 100–120° C. lower than the initial boiling point of the fraction. The work of Dvorkovitz (46) on kerosene does not show such a marked regularity, but there is an average difference between flash and initial boiling points of about 150° C.

Carbonisation.—The degree of carbonisation of lubricating oils, i.e. the amount of asphaltenes produced by exposing the oils to high temperatures, is usually determined simultaneously with the evaporation loss.

The amount of carbonisation was shown by Holde to depend on the proportion of asphaltenes in the original oil; also when an oil was

treated with animal charcoal, the less highly coloured the oil produced the lower was the amount of asphaltenes formed from it at high temperatures. Thus the coloured constituents of oil, which can be removed from an oil by filtration through animal charcoal, may be regarded as an intermediate stage in the formation of asphaltenes; these asphaltic resins, isolated from petroleum by Holde and Eickmann by means of 70 per cent alcohol (63), were found to be intermediate in physical constants, iodine value, and elementary composition to the purified hydrocarbon oil and asphalt.

Although asphaltenes are formed from mineral oils at ordinary temperatures in the presence of sunlight, it is only at temperatures over 150° C. that carbonisation proceeds sufficiently rapidly to be measured in the course of a few hours.

Coking Value.—By the rapid vaporisation of an oil in the absence of air a residue of carbon is left, which is known as the coking value or carbon content of the oil.

The amount of carbon formed in this way is dependent, to a slight extent, on the rate of vaporisation, and the more slowly this is effected the higher the carbon content obtained; it is also dependent on the amount of asphaltenes present in the oil.

Since the process of vaporisation is also a cracking process the higher the boiling point of the oil, the greater is the decomposition, and, other conditions being the same, the higher is the coking value. In the internal-combustion engine all the processes described above take place owing to the wide range of temperatures present.

The following table gives a summary of average temperatures for various parts of internal-combustion engines; of course the temperatures vary to a great extent according to the type of engine and the speed at which the engine is run.

Part	Temperature	
	(*a*)	(*b*)
Maximum temperature of gas	1500° C.	1650°–1850° C.
Piston centre of face	400° C.	400° C.
Piston edge of face	200° C.	—
Centre of exhaust valve	400° C.	706°–752° C.
Centre inlet valve	250° C.	—
Cooling water	65° C.	—
Cylinder head	100°–250° C.	200°–239° C.
Crank case	—	40°–110° C.

(*a*) are measurements on gas engines by Callendar and Dalby (101), Hopkinson (102), and Coker and Scoble (103).

(*b*) are measurements (104, 105, and 106) on gasoline engines.

There is no likelihood of liquid oil films on the cylinder walls being exposed to much higher temperature than 150° C.; the temperature of the oil in the crank case may thus be regarded as slightly below the average temperature of the oil in the engine.

The suction stroke (in the four-stroke cycle) is the only stroke in which there is a smaller pressure in the combustion head than in the crank case, and therefore, during this stroke, leakage of the lubricating oil into the cylinder takes place. The extent of this leakage is dependent on the efficiency of the piston seal, that is, on the viscosity of the oil at the working temperature and on the effectiveness of the piston rings. It is from this oil, drawn by suction past the piston rings and exposed to the high temperatures of the cylinder, that carbon deposits are formed.

Some of the oil will settle on the piston face and cylinder head* and be more or less rapidly carbonised according to the nature of the oil; the asphaltenes formed also decompose giving carbon.

However, the major part of the oil getting into the combustion space is probably present as a fine spray; the heat of the explosion may be sufficient to burn completely the smaller droplets, but the larger droplets will be only partly burnt by the momentary heat of the explosion. Thus carbon and asphaltenes are formed from the oil. If the carbon so formed is light in texture, it will be blown out of the exhaust in the same way as the carbon produced from the fuel when too rich a mixture of fuel in air is used; if, however, dense asphaltic material is formed, in the ensuing compression stroke it will tend to adhere to the piston face and cylinder walls, giving carbon deposits. The carbon deposits in an engine, as is well known, do not consist wholly of carbon, but always contain some asphaltenes, and also metallic particles derived from wear in the engine. In the other three strokes of the cycle, where greater pressure is present in the cylinder than in the crank case, the carbon mixed with oil is forced past the piston rings into the crank case, giving the characteristic black appearance of used oils.

If the views presented here are correct, the suction stroke is the most important of the whole cycle from the point of view of lubrication; the leakage of oil occurring during this stroke is the origin of the carbon deposits found in engines and is also responsible for the total consumption of the oil in the engine. As it is upon the oil spray in the combustion space rather than upon the oil-film on the walls that this carbon formation is mainly dependent, *the rapid carbonisation*

* The oil-film on the cylinder walls is probably but slightly affected by the heat of combustion as the temperature is comparatively low, and therefore no appreciable carbonisation will take place.

of oil, i.e. the coking value, will be a more important factor in the testing of lubricating oils for internal-combustion engines than the gradual carbonisation at lower temperatures. The consumption of oil in the engine will also be more dependent on the viscosity of the oil used than upon its fire test or flash point.

Dilution.—In the compression stroke preceding the explosion some gasoline is absorbed by the oil film in the cylinder, and ultimately the high boiling end fractions of the gasoline may find their way into the crank case and thus cause dilution of the lubricating oil.

There appears to be a limit to the extent of this absorption, which is dependent on the temperature of the oil in the crank case; but as shown by J. B. Garner (see article by Parish, 152) paraffin base oils absorb a greater amount of gasoline under the same conditions than is absorbed by asphaltic base oils of the same distillation range; it was found necessary, therefore, in the specifications for lubricating oils for aircraft engines, to specify for paraffin base oils a somewhat higher viscosity than for the asphaltic base oils (Parish, 152).

When the gasoline is evaporated from the used oil it is found that the residual oil is more viscous than the original oil owing to the accumulation of dissolved asphaltenes and also to the selective evaporation of the more volatile constituents of the oil. Thus cracking of the lubricating oil in the engine probably does occur, but this cracking does not cause dilution as the volatile products are driven out through the exhaust valve or burnt.

From the foregoing discussion it will be seen that the decomposition of oil in an engine can occur in two ways :—

1. Rapid carbonisation due to exposure of the oil in the form of a fine spray or mist to the explosion flame causing incomplete combustion of the oil; the result of such carbonisation is the production of carbon and asphaltic material.

2. Gradual carbonisation of the thin oil film on the piston and cylinder heads at temperatures of 200° to 400° C. giving first asphaltic material, which is changed to carbon by the prolonged action of these temperatures.

In the following investigation the evaporation losses and degree of carbonisation over a wide range of temperatures were determined for a series of lubricating oils from both Texas and Pennsylvania crude petroleums representing asphaltic and paraffin-base crudes respectively; it was thus hoped to determine the general relationship of evaporation

loss and degree of carbonisation to other properties of oils. The physical properties of the lubricating oils were therefore determined and also the distillation range in a vacuum of 4 mms.; a method was also devised for the estimation of the asphaltic resins, as it appeared that both the degree of carbonisation and the coking value would be dependent on the proportion of asphaltic resins in the lubricating oils.

II.

The Estimation of the Asphaltic Resin Content of Lubricating Oils.

Much attention has been given to the standardisation of methods for the determination of asphaltenes and asphaltic resins in petroleum fractions; the methods of Holde depending on the insolubility of asphaltenes in alcohol-ether mixture or in "normal" benzine have probably been most widely used, although other methods dependent on the reduction in volume of the oil on treatment with sulphuric acid are also employed in some countries.

The amount of asphaltene obtained naturally depends on the solvent employed, thus alcohol-ether gives greater values than petroleum ether; other solvents have also been proposed, e.g. butanone (61), amyl alcohol (59) and ethyl acetate (60), but in the case of other liquids than petroleum ether many precautions have to be taken to obtain concordant results.

By *extraction* of lubricating oil fractions with 70 per cent alcohol, Holde and Eickmann (63) obtained a series of resins of which the oxygen content, iodine number and viscosity varied from those shown by refined hydrocarbon oil to those of asphalt. There exists therefore in unrefined petroleum fractions, a number of resinous or semi-asphaltic materials, which, as has been stated by Marcusson (150), probably form the transition stage in the transformation of hydrocarbon oil to asphaltenes.

From the point of view of analysis, a cylinder stock, for example, may be considered as containing two sets of compounds:—*asphaltenes* (determined by means of the benzine precipitation or similar method), and *asphaltic resins*, which are responsible for the dark colour often present even in an oil from which the asphaltenes have been removed. These asphaltic resins may be responsible for the deterioration of an oil in service, and the amount present in oil serves as an

index to the degree of refining; it is therefore of interest to devise a method for their determination whereby concordant results can be obtained.

It is difficult to separate such resins from the hydrocarbon oil owing to similarity in composition, solubilities, and general behaviour towards chemical reagents. Schwartz and Schluter (15) have attempted to accomplish this separation by a method based on a difference of solubility in acetone; they claim that the part soluble in acetone is responsible for the formation of carbon deposits in automobile and gas engines. Other methods such as that of Kissling depend on the removal of these compounds by treatment with alcoholic caustic soda solution; the asphaltic resins are removed, leaving the hydrocarbon oil unchanged. Holde and Eickmann (*loc. cit.*) obtained a series of resinous compounds from petroleum by extracting a mixture of the oil and fuller's earth or animal charcoal successively with petroleum benzine, ether, benzene and chloroform; these resins were similar in general behaviour to those isolated by repeated extractions of petroleum with 70 per cent alcohol.

In the present experimental work the basis of the method is similar to that of Holde (which was an adaptation of Richardson's method of analysis of asphalt (75)); oil is mixed with animal charcoal and the mixture extracted in a Soxhlet with suitable solvents. O'Neill (89) used animal charcoal for this purpose in the following manner:* 5 gms. of the oil to be tested, 25 cc. of gasoline of 88° Be (sp. gr. 0.642) and 5 gms. of animal charcoal were mixed and allowed to stand overnight. The charcoal was then filtered off, washed, dried and the chloroform extract from the charcoal, containing the asphaltic resins, was weighed. The work of Gurwitsch (136 and 137) has shown that whilst asphaltenes and naphthenic acids are irreversibly adsorbed by fuller's earth from benzine solution, lubricating oils and paraffin wax are reversibly adsorbed and can be quantitatively extracted from the fuller's earth with benzine; nevertheless, the adsorbed asphaltenes and naphthenic acids can be readily recovered by the employment of suitable solvents, such as benzene or chloroform. In order to adsorb all the asphaltenes and naphthenic acids it is necessary for a sufficient excess of fuller's earth to be present in the first instance.

Gurwitsch also found that in the case of an almost colourless lubricating oil only very slight amounts were adsorbed from benzine solution by fuller's earth; on the other hand, paraffin wax was adsorbed to a much greater degree.

It will be seen, therefore, that the separation of hydrocarbon oil and asphaltic resin by means of fuller's earth or animal charcoal

* Holde and Eickmann also used a similar method to that of O'Neill.

offers a feasible method for the determination of asphaltic resins in oils. Rakusin (138) has also studied this problem and found that the velocity of adsorption of asphaltic resins by animal charcoal is very high.

Experimental.—In the following work the extraction apparatus employed was the usual Soxhlet form with all ground-glass joints.

Extraction thimbles were filled with a weighed amount of a mixture of oil and animal charcoal of known composition; the thimbles were supported in the Soxhlet by means of a copper wire spiral, of which the uppermost ring lightly gripped the upper part of the thimble, so that the thimbles were raised about 2 cms. above the bottom of the extraction cup. It was found that by means of this device very efficient extraction was possible; at each emptying of the Soxhlet the liquid loosely retained by the material in the thimble was, to a great extent, drained away, and thus when further liquid condensed there was comparatively little contamination of this condensate with the previous extract.

For the first extractions petroleum ether of boiling point 40°–60° C. was used, and after the extraction had been carried on for the desired length of time the petroleum ether extract was transferred to a tared flask and the Soxhlet flask washed out with petroleum ether. The combined extract was then evaporated at 100° to constant weight. From these figures the percentage of oil recovered was calculated.

After this series of extractions the thimble was heated in a hot air oven for a few minutes to evaporate the petroleum ether and then the extraction process was resumed as before, using chloroform, however, as solvent.

In the preliminary experiments both fuller's earth and animal charcoal were used as absorbents for the oil. Some experiments were also made in which the oil was mixed with fuller's earth and placed in a small thimble, and this latter was then placed in a larger thimble and the intervening space filled with animal charcoal; such an arrangement gave very satisfactory results on extraction, but was discarded on account of the difficulties involved in duplicating the results with other animal charcoal and fuller's earth. Eventually the method described above was adopted.

The animal charcoal was about 15–20 mesh and was heated to redness in the absence of air prior to use; by blank experiments it was shown that benzine soluble and chloroform soluble materials were not present in this charcoal.

In the experiments described below, lubricating oil fractions from

Texas crude, and Penna. cylinder stock were used. The results of physical tests carried out on these oils are shown below :—

TABLE I.

	Texas		Cylinder Stock
	Medium	Aero	B
Specific Gravity 15°/15° C.	0·934	0·952	0·911
Baume Gravity 60° F.	19·9	17·1	23·7
Flash Point (Cleveland Cup)	163° C.	223	315
Fire Test (Cleveland Cup)	188° C.	256	360
Viscosity (Saybolt at 212° F.)	45	79	225

In Table II is tabulated the percentage of oil recovered, after extraction for different lengths of time, from a series of mixtures of the aero Texas lubricating distillate with animal charcoal.

TABLE II.

Gms. of oil to 100 gms. of charcoal	Extraction Time (hours)					
	½*	¾*	1	2	4	8
1·62	78·1	82·0	83	84·5	86	87·5
4·99	84·1	86·9	88·1	89·5	90·6	91·3
10·06	87·9	90·6	91·5	92·9	93·7	94·3
18·2	92·3	93·3	94·1	94·4	94·7	95·4
37·3	93·0	94·2	94·6	94·7	95·1	95·6
74·6	86·3	95·5	95·6	95·8	96·0	96·3

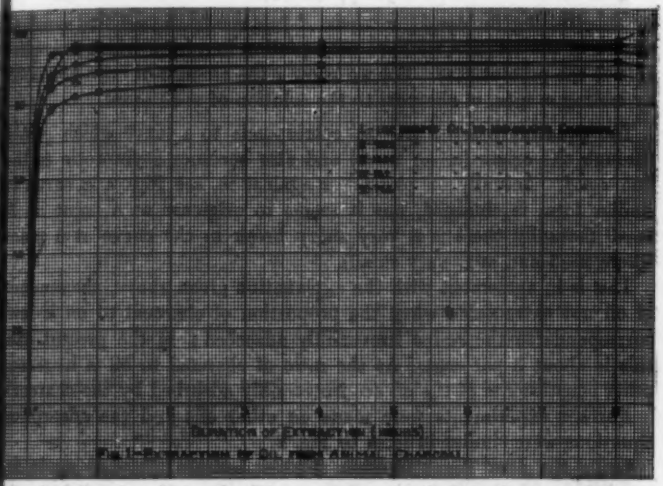
These results are shown graphically in Fig. 1, and it will be seen that as the percentages of oil to animal charcoal is increased the curves become closer together and also much flatter. There is no sharp break present in any of the curves, and this is as would be expected, since asphaltic resins varying from hydrocarbon oil to asphalt in character are contained in the oil.

Mechanism of the adsorption and extraction processes.—When the oil is mixed with the charcoal the resins are immediately adsorbed, and thus there is present a mixture of charcoal+resins and absorbed oil; the process of extraction with petroleum ether is mainly in the removal of this loosely held oil, although a small amount of resins is probably also dissolved, particularly in the later stages of the extrac-

* These periods of less than one hour are not, of course, exactly measured. The rate of extraction was such that the Soxhlet emptied 4–6 times in 1 hour, so that it will be seen that very efficient extraction was obtained.

ion (in all cases a small amount of material was extracted in the 4–8 our period of the extraction, i.e. the curves never became actually uite parallel to the time ordinate). These extraction curves correspond approximately to a series of hyperbolas of the general form $(A-x)\ T=c$ where $A=\%$ extracted at end of eight hours, $x=\%$ of xtract at time T, and c is a variable dependent on the percentage of il in the charcoal and oil mixture.

After eight hours' extraction very little further increase occurs in he percentage of oil recovered, and the difference in weight of oil sed and oil recovered corresponds to the amount of asphaltic resin



dsorbed by the charcoal. The amount adsorbed varies according to he proportion of oil to charcoal in the mixture extracted, and there ppears to be a lower limit in the amount adsorbed as the concentraion increases.

It is somewhat difficult to explain these results, but it is evident hat the animal charcoal irreversibly adsorbs a large part of the resins resent in the oil (probably by precipitating them from colloidal olution), and the amount thus adsorbed corresponds to the lower imit alluded to above; as the proportion of animal charcoal to oil s raised, other constituents of the oil apparently react* in the presence

* Gurwitsch showed that amylene is polymerised by means of animal charcoal nd a similar change may occur here; he also showed that on mixing oil ecolorised with charcoal with the resins recovered from the charcoal, an oil of arker colour than the original oil was obtained; this indicated that a change in he character of the oil was produced in treatment with animal charcoal.

of the animal charcoal and become incapable of dissolving in petroleum ether, and thus a higher asphaltic resin content is obtained.

From these experimental results it was decided to adopt the proportion of 20 gms. of oil to 100 gms. of charcoal and extract for two hours as a test for the determination of asphaltic resins in lubricating oils.

If the general adsorption equation $x/m=pc^{\frac{1}{n}}$, where x is the amount adsorbed when m of adsorbent is added to a solution of concentration c (p and n being constants), is rewritten

$$x/m=p\ (A-x)^{\frac{1}{n}}$$

by substituting for $c=A-x$ where A represents the original concentration of the solution we have the equation in a form which is applicable to the present case. For we know x the amount of resin adsorbed by adding m gms. of charcoal to the solution of resin in oil.

The equation $x/m=p\ (A-x)^{\frac{1}{n}}$ corresponds to a curve which passes through the origin ($x=o$, $m=o$) and also becomes asymptotic to the line $x=A$. Actually on plotting x against m, see Fig. 2, a curve of similar form is obtained, but it seems to originate at a point $x=3$, $m=0$ (actually there is a very sharp break in the curve at a point where $x=3$ and m is very small).

This is in agreement with the explanation given above, the amount of oil not extractable when the proportion of charcoal to oil is low corresponds to the resins irreversibly adsorbed; in the present case this is about 3 per cent. As the ratio of charcoal to oil is increased other constituents of the oil are irreversibly adsorbed by the charcoal.

Further experiments were made on other oils and the adsorption equations were similar in form to Fig. 2.

Using the aero Texas fraction, Soxhlet extractions were made for two hours with the proportion of 20 gms. of oil to 100 gms. of charcoal; the chloroform extract of the charcoal was then determined by four hours' extraction. The oil obtained by evaporation of the petroleum ether extract was again treated with animal charcoal and extracted with petroleum ether; the oil recovered from this operation was treated for the third time in the same way. The proportions of oil extracted and of resin are recorded in Table III.

TABLE III.

	Oil.	Resin.	Total.
1st Extraction	94·7	3·8	98·5
	95·1	3·8	99·0
2nd Extraction	97·5	2·2	99·7
	97·3	2·1	99·4
3rd Extraction	97·8	1·3	99·1

These results are typical of other experiments. It was found that 2 per cent of oil was not recoverable by means of petroleum ether and that the total oil+resin content generally was at least 0·5 per cent short of 100. It is probable that in the third extraction the resin was produced by polymerisation as very slight decolorisation of the oil was effected.

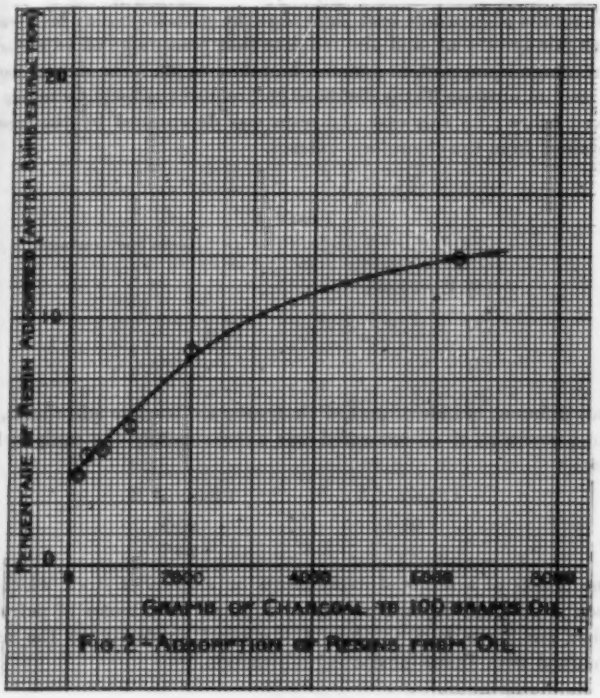


Fig. 2.—Absorption of Resins from Oil.

With oils of flash point below 200° C. it was found practically impossible to dry to constant weight owing to notable losses occurring by evaporation at 100° C. It was necessary, therefore, in these cases to rely on the resin extract as obtained by the extraction with chloroform.

In the following table are given the oil extracted and the resin content of aero Texas oil and of partly refined products obtained from it.

TABLE IV.

	Oil extracted		Resin (chloroform extract)		Total
(1) Unrefined	94·8	95·1	3·8	4·2	98·7
	94·7	94·4	3·9	4·3	
(2)	94·7	94·9	3·9	4·2	98·7
(3)	96·7	96·8	2·5	2·5	99·3

The results of duplicate tests show that the estimation may be repeated with fair agreement, and also indicate that percentage oil extracted + percentage resin may, in general, be taken as 99. The determination of resin in medium Texas distillate and refined products therefrom are given below; in this case the resin was determined by the amount obtained from the chloroform extract.

TABLE V.

	Resin (percentage)
(1) Unrefined	2·6
	2·6
(2)	2·5
(3)	1·2
	1·3

Two different brands of animal charcoal were tried as adsorbents, and the percentage of oil recovered was approximately the same in both cases.

Charcoal A	Charcoal B
94·4	95·1
94·8	94·7

The results of a series of experiments on a cylinder stock which had been freed from asphaltenes by solution in 20 volumes of petroleum ether are given here to show the general similarity to the results obtained with Texas lubricating oil fraction.

TABLE VI.

Gms. of oil to 100 gms. of charcoal	Extraction Time (hours)					
	½	¾	1	2	4	8
4·95	85·3	88·5	89	89·5	90	90·5
11·2	88·3	89·4	89·8	90·5	91·3	91·8
16·5	87·6	90·9	91·9	92·5	92·9	93·3
36·3	85·8	93·4	93·8	94·1	94·3	94·5

TABLE VII.

	Texas Crude Lubricating Oil Fractions					Pennsylvania Crude Lubricating Fractions			Cylinder Stocks	
	Light	Medium	Heavy	Aero Distillate	Aero Oil	Wax Distillate	Non Viscous Neutral	Viscous Neutral	A	B
Specific Gravity 15°/15° C. ..	0·930	0·934	0·938	0·952	0·949	0·849	0·853	0·871	0·894	0·911
Baumé Gravity 60° F.	20·5	19·9	19·2	17·1	17·5	34·9	34·1	30·7	26·6	23·7
Flash point ° C.	155	163	174	223	210	100	168	213	277	315
Fire Test ° C.	175	188	200	256	245	146	194	243	315	360
Viscosity 30° C.	272	358	574	—	—	75	88	255	—	—
Saybolt 100° F.=37·8° C. ..	162	225	340	—	—	65	72	172	—	—
60° C. ..	72	87	109	471	435	46	485	81	596	1250
212° F.=100° C. ..	41	45	50	79	72	36	37	46	131	225
120° C. ..	37	39	41	57	56	33	34	40	85	120
Distillation Initial at 4 mms.	88	102	114	195	169	50	112	180	200	234
pressure 5%	129	136	146	220	204	120	158	206	259	306
10%	145	148	164	229	212	141	166	212	273	325
25%	166	170	190	238	224	160	178	220	299	—
50%	191	199	220	250	237	200	194·5	238	340	—
75%	211	221	242	264	248	230	207	256	—	—
Coke value (Conradson)	0·02	0·04	0·07	0·30	0·20	0·02	0·02	0·17	2·6	4·9
Asphaltenes	—	—	—	—	—	—	—	—	—	0·87
Resin Content (1)	1·20	2·6	2·4	4·3	2·5	1·4	—	—	5·1	—
(2)	0·6	1·2	1·2	—	—	1·25	—	—	—	7·0
(3)	—	—	—	—	—	0·71	—	—	—	4·0

As a result of these experiments the following method of determining asphaltic resins in oils was used in order to determine whether any relation exists between the asphaltic resin content of oils and the degree of carbonisation which occurs with these oils at high temperatures. The accuracy obtainable in the asphaltic resin content should be about $\pm 0{\cdot}25$ per cent.

About 10 gms. of animal charcoal are weighed out in a tared 100 cc. beaker, 2 gms. of oil added, and the beaker reweighed. A Soxhlet thimble and small piece of cotton wool are now weighed together; after thorough mixing of the animal charcoal-oil mixture, this is transferred by means of a glass rod to a thimble and the latter reweighed. (The cotton wool is placed on top of the thimble and causes diffusion of the petroleum ether in the extraction.) By calculation, the amount of oil used may be ascertained.

After two hours' extraction the petroleum ether extract is transferred to a weighed flask, all the liquid in the Soxhlet cup poured into the Soxhlet flask and then into the weighed flask. The Soxhlet flask is washed out twice further with the petroleum ether, and the united petroleum ether washings and extract evaporated to constant weight on a waterbath. Small traces of petroleum ether present at the end of the evaporation were removed by a stream of air.

The percentage of oil recovered is then calculated. The resin content as determined in this way is not recommended for a general test, as to obtain concordant results careful attention must be paid to the technique; it is, however, useful for purposes where it is desired to follow the change in the character of oil and the process of carbonisation is slow, or where it is desired to distinguish between two oils of different resin content. In this latter instance, there may, however, be a considerable difference in the colour of the oil without a correspondingly large difference in the resin content.

The results recorded in this section on the experimental work in connection with the determination of the resin content of oils are also of interest as related to the decolorisation of lubricating oils by filtration through animal charcoal or fuller's earth.

III.

The Carbonisation and Evaporation Losses of Certain Oils from Penna. and Texas Crudes.

The oils used in the following work were lubricating fractions from Texas crude petroleum and lubricating fractions and cylinder stocks from Pennsylvania crude petroleum. The results of physical tests which were carried out on these oils are shown in Table VII; the oils,

with the exception of the aero oil, were as distilled and not refined by chemical treatment or filtration.

The resin content of the unrefined distillate or cylinder stock (1), and of products obtained from it by treatment with sulphuric acid and caustic soda solution, or by fuller's earth (2), and (3), are recorded for some of the oils; in some cases the resin content was obtained by extraction with chloroform as already described, and in other cases it was obtained from the percentage of oil recovered by subtracting this number from 99·0 per cent.

The flash point and fire test were taken in the Cleveland open Cup.

The viscosities were taken using a Saybolt viscosimeter, but if desired these values can be readily calculated to Redwood values, using the conversion factors of Herschel (153).

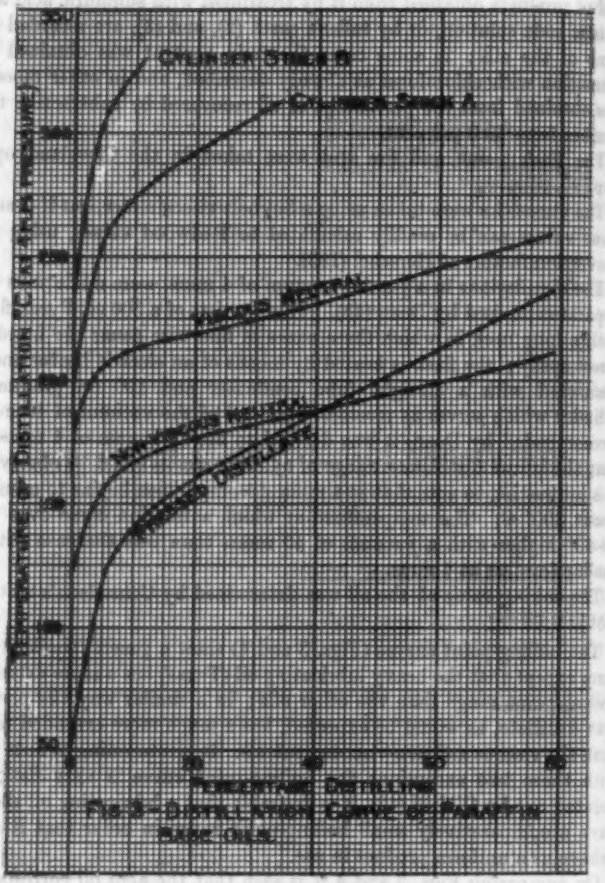
The distillations in a partial vacuum of 4 mms. were made with the apparatus devised by Dean (45). This consists of a 500 cc. Pyrex flask with a long neck in which three cones of fine wire gauze are fitted to arrest spray; the flask is heated by means of an electric heater and is connected with a straight tube condenser and 100 cc. graduated cylinder which serves as receiver. Instead of the vacuum of 40 mms. recommended by Dean, it was decided to use a vacuum of 4 mms. so that the initial distillation range of cylinder stocks could be observed; it is interesting to note that at 4 mms. decomposition begins to occur at about 300° C. The temperature at which a fraction came over was 50-60° higher with a vacuum of 40 mms. than was the case with a similar fraction at 4 mms.

The coking value of the oil was determined by Conradson's method (55b).

The boiling-point curves (Figs. 3 and 4) show a general similarity in form except that the heavy lubricating oil (Texas) has a more extended boiling-point range than the other oils; in a similar way the pressed wax distillate, as would be expected, has a much more extended range than the viscous and non-viscous neutrals. It is interesting to note that with these two exceptions the boiling-point curve is very flat; as pointed out by O'Neill (42), it is desirable that a lubricating oil should have a comparatively small boiling-point range in order that it may behave as a uniform product in use.

On comparing Figs. 3 and 4 it is seen that the aero oil corresponds very closely in boiling point with the viscous neutral, and hence we may institute comparisons between these two oils of different stocks, e.g. as regards viscosity and carbonisation; the non-viscous neutral is somewhat similar to both the heavy and medium distillates of the Texas crude petroleum.

The relationship between flash point and boiling point is, as already pointed out, dependent much more on the boiling-point range of the first 10 per cent than of the remaining 90 per cent; if we compare the



flash-point and fire-test temperature with the temperature of distillation when the initial 5 per cent fraction has distilled over at 4 mms. omitting the pressed wax distillate, the difference is 15° C ±12° C. in the case of flash point and 46° ±12° in the case of fire test. There is a tendency for the difference between flash point or fire test and temperature of

distillation to become greater, the higher the temperature of distillation. While the number of oils examined is too small on which to base a generalisation of the relation between flash point and boiling point, the

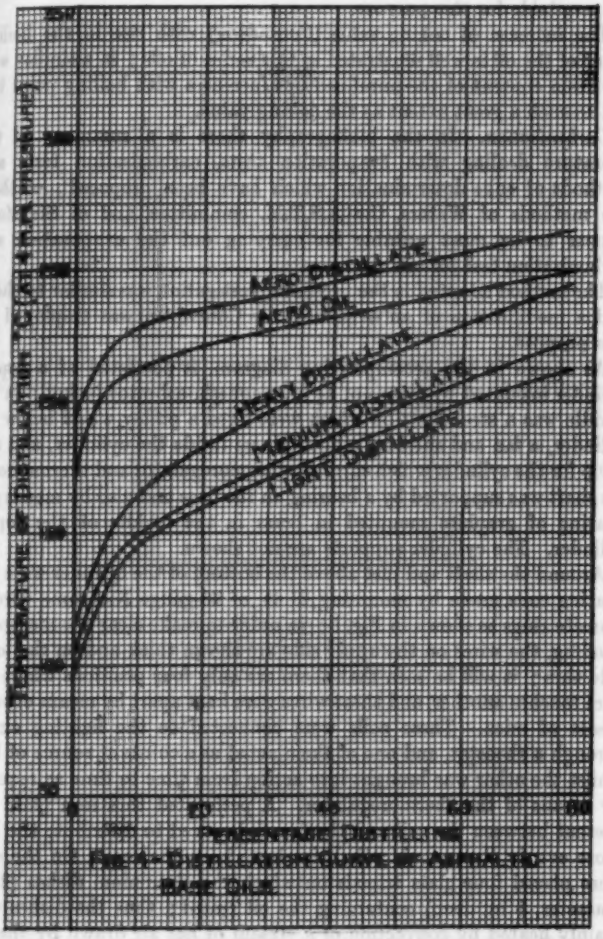


FIG. 4.—DISTILLATION CURVES OF APPROVED BASE OILS.

figures are given as an indication that some such relationship does exist, although it may vary both with the temperature of distillation and the range of distillation of the oil.

The temperature of distillation at 760 mms. (assuming that no decomposition occurs) cannot readily be calculated from the temperature of distillation at 4 mms. as data dealing with lubricating oils are not available for this purpose.

The increase of coking value (Conradson) with rise in the boiling point of the oil is well illustrated in this series of oils; in a similar way the resin content of the unrefined oils increases with boiling point but not to such a great extent as the coking value.

Carbonisation.—In the bibliography there is a summary of the literature dealing with evaporation tests, carbonisation tests and methods of coke determination which have been proposed; of these the methods of Waters, the A.S.T.M. committee, and of Stratford, appear to be most suitable for carrying out the evaporation and carbonisation test for oils.

The method adopted in the present investigation was similar to these, and a modification of an oven used by Conradson was employed for this purpose.

As shown in the accompanying diagram, it consisted of a copper cylinder insulated by means of 1½ in. magnesia-asbestos jacket; in the middle was a steel shaft on which were fixed a pulley wheel below the cylinder, a fan and shelf for oil containers inside the cylinder, and also a top for the cylinder which carried a thermoregulator and thermometer. Its shaft was supported by a bearing on the base and also by means of a bearing of graphite mounted in brass in the middle of the copper cylinder. The cylinder supports are not shown.

Around the shaft and just above the bottom of the cylinder were two heating coils made by mounting 21 ft. of 26-gauge Nichrome wire on transite rings as shown in Fig. 5; in order to make clear the method of winding, the wires on the upper side are shown thick and on the lower side thin; it will be seen that there are only four positions where one wire touches another, and these wires were kept apart by means of small pieces of mica. These coils were connected to the lighting circuit through a rheostat, and one of them acted as a constant source of heat whilst the other was brought into action from time to time as required by means of the thermoregulator. A perforated thin iron plate was present between the coil and the fan and served to distribute the heat more evenly than would otherwise have been the case. On the shelf were placed four glass tripods on which the aluminium dishes (2½ in. diameter, ½ in. deep) containing the oil rested; thus the dishes were mainly heated by convection of a stream of hot air drawn by the fan through a hole in the bottom of the copper cylinder and not by conduction. The shaft was rotated at a speed of 5–6 revolutions per minute.

The oven could be easily regulated at 250° C. to ±2° C. and a temperature of 350° C. could have been obtained if desired. Approximately 20 gms. of oil was used in each test.

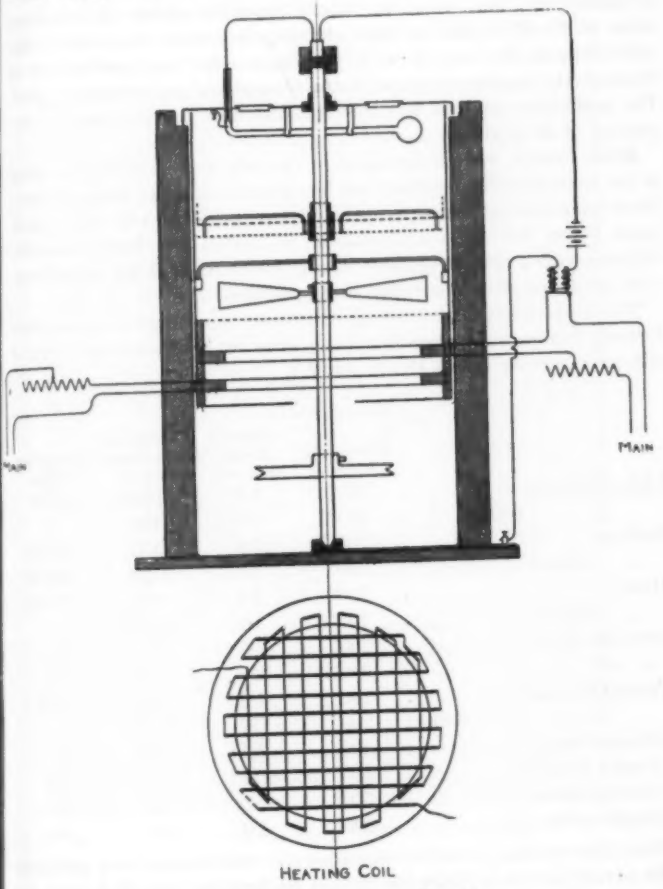


FIG 5 HOT AIR OVEN

Fairly concordant results could be obtained if four evaporations of the same oil were carried out at the same time. The oven was always heated to the desired temperature before introducing the dishes containing the oils to be tested.

From the difference in weight of the aluminium dishes before and after heating, the evaporation loss was calculated as a percentage.

The proportion of asphaltenes in the residual oil was determined by dissolving 5 gms. of oil in twenty times its volume of petroleum ether of 40–60° C. B.P.; after standing overnight, the asphaltenes were filtered off, washed with petroleum ether and redissolved in benzene, the benzene evaporated, and the residual asphaltenes weighed. The asphaltene content was then calculated as a percentage on the amount of oil originally used.

Resin Content and Carbonisation.—The oils were tested by heating in the oven, already described, for four hours at definite temperatures; these temperatures varied with the oil used—thus for oils with a flash point below 200° C., a temperature of 200° C. was found suitable, whereas with a filtered product from cylinder stock B, no asphaltenes were produced after four hours' heating at 300° C.

The temperature of the carbonisation test, percentage of asphaltenes formed, and in some cases Conradson coke for unrefined and refined oils, are shown in Tables IX, X and XI.

TABLE VIII.

	Heated for 4 hours at	Asphaltic Resin Content.	Percentage Asphaltenes formed.	Conradson Coke.
Light distillate	200°	1·2	1·36	0·19
„ refined	200°	0·6	0·50	—
Medium	200°	2·6	0·91	0·045
„ refined	200°	1·2	0·38	0·038
Heavy	200°	2·4	0·60	0·075
„ refined	200°	1·2	0·40	—
Aero distillate	250°	4·3	1·03	0·3
„ oil	250°	2·5	0·60	0·2
Pressed wax distillate	200°	1·40	0·27	0·02
„ „ refined	200°	0·7	0·16	—
Cylinder Stock A	300°	5·11	2·27	2·6
Cylinder Stock B	300°	Asphalt 0·87	2·2	4·9
Cylinder refined (1)	300°	7·0	0·1	3·0
Cylinder refined (2)	300°	4·0	*nil*	1·4

From these results it will be seen that the resin content is a guide to the percentage of asphaltenes formed on heating, provided that we are dealing with oils of similar boiling-point ranges; it cannot be claimed that there is any quantitative relationship as the resin value is only approximate. Nevertheless it indicates that ***both the Conradson coke and the carbonisation which occurs on heating are dependent on the amount of asphaltic resin originally present in the oil.***

Engler (56) found that, in general, the coke value of an oil was proportional to the amount of asphaltic resins in the oil. In a more recent paper it is noted that the coke value is dependent on the hard and soft asphalt contents (56a).

Evaporation Loss and Carbonisation.—The evaporation loss and carbonisation (% asphaltenes formed by heating) were determined for

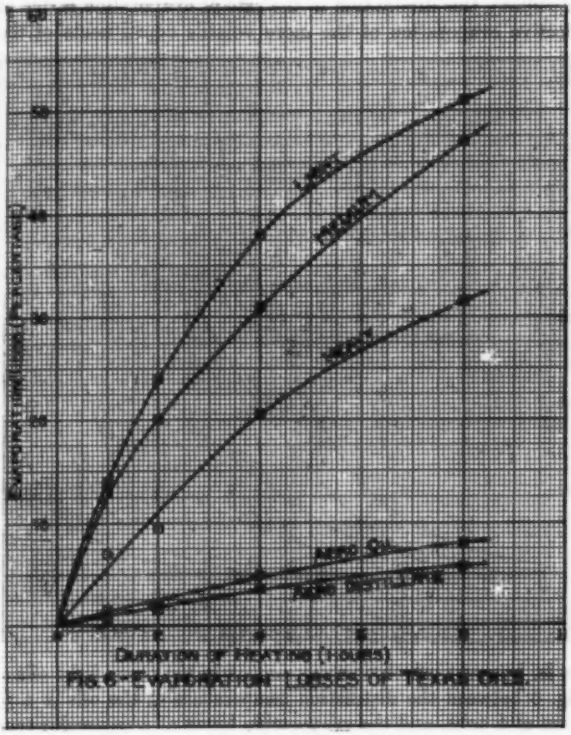
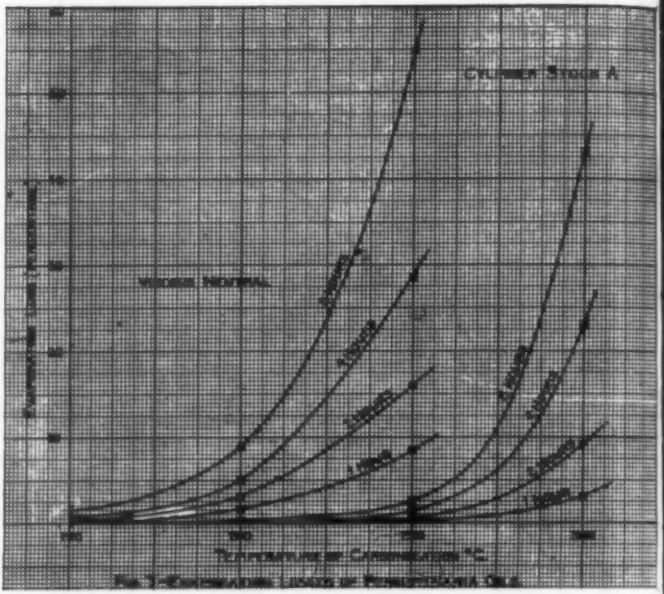


FIG. 6.—EVAPORATION LOSSES OF TEXAS OILS.

all of these oils at a number of different temperatures; the results obtained were concordant to the extent prescribed in the A.S.T.M. method (23d), but occasionally it was necessary to reject one value out of four determinations, owing to its being much too high or much too low.

The evaporation losses occurring when the oils were heated at different temperatures for various lengths of time are summarised in Tables IX, X, and XI.

In Fig. 6 the evaporation loss for the series of Texas oils at 200° is plotted against the duration of the heating. When comparatively small losses occur, the loss by evaporation is proportionate to the duration of heating; in the case of larger evaporation losses, the rate of evaporation diminishes as the duration of the heating is prolonged. In the case of an oil of extended boiling-point range, e.g. the pressed wax distillate, this diminution in the rate of evaporation is due partly to selective evaporation of the more volatile constituents of the oil.



There is, however, an obvious agreement in the case of the oils shown in Fig. 6 between the distillation temperature of the oils in a partial vacuum of 4 mms. and the evaporation losses at a particular temperature; the higher the distillation temperature, i.e. the higher the fire test of the oil, the lower is the volatility. This result applies to all the oils tested, Pennsylvania and Texas. As already noted, if we compare viscous neutral oil with aero oil and aero distillate, we see that the boiling-point range of the former is very nearly intermediate between the two latter; the evaporation losses of the viscous neutral are also intermediate at temperatures of 150°, 200° and 250° C. to those of the latter. A similar comparison holds with the non-viscous neutral oil

and the medium and heavy Texas oils. Thus *in the case of the oils tested, the evaporation losses of lubricating oils of similar boiling-point range were approximately the same, whether the oils were derived from Texas or Pennsylvania crude.*

On referring to Fig. 7 it is seen that a rapid increase in volatility occurs with increase in temperature; the volatility of the oil increases very rapidly in the neighbourhood of the fire test temperature, whereas at temperatures of 50° C. below the fire test the evaporation loss in four hours is only about 5 per cent.

Table IX.

EVAPORATION LOSS AND CARBONISATION OF PENNSYLVANIA OILS.

Hours of heating	Pressed Distillate		Non Viscous Neutral				Viscous Neutral				
	200°		150°		200°		150°	200°		250°	
	Loss	Asphalt	Loss	Asphalt	Loss	Asphalt	Loss	Loss	Asphalt	Loss	Asphalt
1	15	0·17	—	—	7	—	—	1·8	nil	8·5	nil
2	28	0·25	1·85	nil	18	0·5	—	3·1	„	16	0·3
4	39	0·31	4·5	„	30	0·6	0·8	5·9	0·2	29	0·5
8	53	0·61	7·0	0·3	52	0·9	1·5	8·8	0·9	55	1·1

Hours of heating	Pressed Distillate Refined		Cylinder Stock A					Cylinder Stock B				
	200°		150°	200°	250°	300°		150°	200°	250°	300°	
	Loss	Asphalt	Loss	Loss	Loss	Loss	Asphalt	Loss	Loss	Loss	Loss	Asphalt
1	13	—	—	—	—	3·3	0·5	—	—	—	0·65	1·2
2	23·5	—	—	—	—	8·2	1·4	—	—	—	1·3	1·9
4	35·5	—	0·2	0·65	1·3	23	2·3	nil	0·05	0·5	5·5	2·2
8	52	0·5	0·25	0·9	2·4	43	4·9	„	0·10	0·9	11·5	5·3

Table X.

EVAPORATION LOSS AND CARBONISATION OF TEXAS OILS.

Hours of heating	Light Distillate		Medium Distillate			Heavy Distillate			Aero Distillate				
	200°		150°	200°		200°		150°	200°			250°	
	Loss	Asphalt	Loss	Loss	Asphalt	Loss	Asphalt	Loss	Loss	Asphalt		Loss	Asphalt
1	14	—	—	13	trace	6·7	0·1	—	0·87	4·7R*		7·0	0·23
2	24	0·7	—	20	0·28	9·5	0·2	—	1·6[illegible]	5·8R		16	0·6
4	38	1·4	7·5	31	0·9	20·[illegible]	0·6	0·17	3·7	0·7		37	0·9
8	51	3·0	10·5	47	1·3	31·5	1·1	0·34	5·4	1·1		55	—
16	—	—	—	—	—	—	—	—	—	—		71	—

* R indicated that no asphalt was formed, 4·7R = resin content of oil. These figures and those for aero oil show the gradual increase which takes place at high temperatures.

TABLE XI.

EVAPORATION LOSS AND CARBONISATION OF TEXAS OILS.

Hours of Heating	Light Distillate Refined		Medium Distillate Refined			Heavy Distillate Refined		Aero Oil				
	200°		150°	200°		200°		150°	200°		250°	
	Loss	Asphalt	Loss	Loss	Asphalt	Loss	Asphalt	Loss	Loss	Asphalt	Loss	Asphalt
1	13·5	nil	—	11	nil	6	nil	—	1·5	3·0 BR	10	nil
2	22	0·21	—	17	„	10	„	—	2·0	4·5 BR	16	0·10
4	37	0·5	7·2	30	0·5	20	0·4	0·4	5	8·0 BR	39·5	0·6
8	46	0·7	10·3	44	1·3	28	0·6	0·8	8	0·7	60	—

The rate of evaporation of these oils can be approximately expressed by the equation $\log\left(\frac{100}{100-x}\right)=kt$, where x represents the evaporation loss in time t and k is a constant for any particular temperature; k decreases uniformly as the distillation range of the oil is increased.

It is important to note that not only the temperature of distillation but also the extent of the distillation range may have marked effects on the evaporation losses; here most of the oils have similar boiling-point ranges.

Asphaltene Formation.—The proportion of asphaltenes formed at a given temperature increases much more rapidly than the evaporation loss, and in a given time the amount of asphaltenes present increases very rapidly with rise in temperature. Thus although there is no definite relation between asphaltene formation and evaporation loss there is a general parallelism.

On comparing a similar series of oils which have been heated to the same temperature, it is seen that the amount of asphaltene formed in a given time is lower the higher the boiling-point of the oil; that is *for similar oils there is a general relationship, that the higher the flash-point of the oil the lower is the amount of asphaltenes formed in a given time at a given temperature.* This statement appears at first sight to be in direct contradiction to a statement of Waters' (38, p. 19); his results are, however, explained by the fact that the refined oils (Table XIV *loc. cit.*) show less asphaltene formation under similar conditions than the unrefined oils, and this is dependent on the asphaltic resin content of the oil.

The rate of asphaltene formation can be expressed mathematically by the equation $y=Kt^2$ where y is the amount of asphaltene formed after heating, for time t and k is a constant for any particular oil at a definite temperature. The results of Waters' experiments (38) are

shown in the following table, which shows the close agreement between calculated and experimental results.

TABLE XII.

Hours of heating at 250°	Oil (1) $K=\frac{1}{45}$		(2) $K=\frac{1}{40}$		(3) $K=\frac{1}{25}$	
	Found	Calculated	Found	Calculated	Found	Calculated
1	0·03	0·02	0·04	0·025	0·04	0·04
2	0·10	0·09	0·10	0·10	0·16	0·16
3	0·14	0·20	0·17	0·22	0·36	0·36
4	0·34	0·35	0·37	0·40	0·60	0·64
5	0·51	0·55	0·54	0·62	1·02	1·00
6	0·63	0·80	0·94	0·92	1·37	1·56
7	1·26	1·09	1·25	1·25	2·01	1·96

The results of Waters for other oils show values ranging from $K=$ 0·003–0·115 *and the value decreases almost uniformly with rise in flash point and fire point.*

The carbonisation tests in the present investigation are not so extensive as those of Waters', but they are in general agreement with this equation.

The amount of asphaltene formed by heating an oil may thus be regarded as dependent on two factors :—

(1) The boiling-point range of the oil

(2) The impurities present in the original oil.

The effect of factor (1) is, as already stated, that the higher the boiling point of the oil the lower is the amount of carbonisation which will take place under the same conditions. It is therefore unfair to compare two oils of very different boiling point at the same temperature, as the lower boiling-point oil may be more highly refined than the other oil and yet give higher asphaltene formation. Apparently factor (2) is more important in the formation of asphaltenes than the first factor ; under impurities are included the asphaltic resins and particles of foreign matter which, as shown by Waters, may act catalytically and cause the formation of large amounts of asphaltenes. In the case of the oils tested here, the amount of asphaltic resin present was sufficient, however, to account for the amount of asphaltene formation. Waters has shown that the action of sunlight on oils is primarily an oxidation process, carbon dioxide and water being given off and an increase in weight of the oil taking place due to the production of resins. The

rate of increase of weight becomes less as the time increases, which would seem to indicate that here the oxidation process is concerned mainly with asphaltic resins or easily polymerisable constituents of the oil. The action of high temperatures on oils is similarly mainly an oxidation process, for asphaltenes are formed only slowly in the absence of air; this process causes an increase in the amount of asphaltic resins and these are changed to asphaltenes as the heating is continued; thus it is only after the carbonisation process has been effected for some time that asphaltenes are detected. It is possible that the asphaltic resins or asphaltenes act catalytically in accelerating the carbonisation process, for in connection with the oxidation of paraffin wax to fatty acids the oxidised product is said to act as catalyst (121). The amount of asphaltenes present increases very rapidly as the temperature or time of heating, i.e. of evaporation loss, is increased; the reason for this appears to be that a concentration of asphaltenes in the residual portion occurs, and also that the so-called evaporation process is not a simple evaporation. In this latter, decomposition of the hydrocarbons takes place with the production of asphaltenes, and therefore the lower the temperature of heating the greater is the production of asphaltenes for a given evaporation loss.

In the testing of oils by the carbonisation test the temperature used should obviously approximate to that which the oil is to be subjected in use; if, however, this is not practicable, then the carbonisation should be carried on at a temperature at which say 20–40 per cent evaporates in four hours. Thus it will be found that in practice temperatures of 200°, 250° and 300° will suffice for most oils, but that one temperature will not be adequate for the testing of all oils.

Laboratory Tests and Engine Tests.—At this point it is interesting to consider the results of the engine tests made in connection with Liberty Aero Oil (152); these tests were designed to develop a suitable mineral lubricating oil for use in stationary aero engines of the vertical type. For this purpose eleven oils which had been already found suitable by oil refiners were investigated, and five different aero engines were used. Special precautions were taken in these comprehensive tests to ensure that factors other than the lubricating oil were as uniform as possible.

The oils used were distillates from asphaltic base petroleum and stock-blended oil from paraffin and mixed base petroleums. On careful comparison of these tests it will be found that the distillates gave much more satisfactory service on all the engines—better lubrication and fewer troubles owing to carbon deposits—than the blended oils; apparently no tests were made with paraffin base distillates, presumably owing to the viscosity of such oils being too low for this purpose.

The Conradson coke test was found to be a better criterion of the behaviour of the oil in the engine, as regards the formation of carbon deposits, than the carbonisation test; this behaviour is in agreement with the theory advanced in the introduction, on the formation of carbon deposits in engines from lubricating oils.

As is seen from the results given in this section, the coke test gives lower figures with distillates than with cylinder stocks, and the carbonisation test gives lower figures with cylinder stocks than with distillates.

From the results given in the engine tests on Liberty Aero Oil, however, it appears that in appraising the value of an oil from the Conradson coke determination, the value obtained from low specific gravity oils must be regarded as equivalent to a somewhat lower coke value for high specific gravity oils, that is oils of higher coke value are permissible from low specific gravity oils than from high specific gravity oil.

The most satisfactory oil tested (of 0·948 sp. gr. and 73 Viscosity (Saybolt) at 100° C.) gave a large amount of carbon which came out of the exhaust; incidentally, in connection with the recent work of Wells and Southcombe and others (151) on the effects of small amounts of fatty acids on the lubricating qualities of oils, it is interesting to note that this oil had a high acidity. Oils of high acidity could not be used for the lubrication of aircraft engines, however, as the used oils were reclaimed by means of a water and soda ash treatment.*

Since a suitable distillate appears to give more efficient lubrication than a blended oil of bright stock and distillate, it would seem that for the lubrication of aircraft engines, where absolute reliability is expected of the engine at all times, a paraffin base distillate of sufficiently high viscosity would be of great value; it would present the advantage of much smaller change in viscosity with temperature than is the case with asphaltic base distillates. Such an oil could be obtained by a combined process of steam and vacuum distillation. The high boiling points of the blended oils commonly used for the lubrication of aircraft motors are obviously not required, since castor oil, which is equally efficient, undergoes rapid polymerisation at temperatures of 300° C.; castor oil has the advantageous property, however, of low evaporation loss even at 250° C. which may partly account for its successful use in these engines. A paraffin base distillate of the necessary viscosity would also possess comparatively low evaporation loss at this temperature, and there should be no insuperable difficulty in the preparation of such an oil of suitable cold test.

* For description of this method see J. R. Battle, *National Petroleum News*, March 3, 1920, page 77.

SUMMARY.

1. A method of determining the asphaltic resins in lubricating oils has been devised by utilising the selective absorbent power of animal charcoal for these resins. It has been shown that in similar oils the resin content influences both the extent of the carbonisation at high temperatures, and the coke value (as determined by Conradson's method).

2. Experimental work on the evaporation and carbonisation of a series of lubricating oils, derived from Texas and Pennsylvania crudes, shows that—

(*a*) Oils of similar distillation range from the different crudes have similar evaporation losses at the same temperature of evaporation.

(*b*) There is direct connection between evaporation loss and the fire test of an oil, but the original content of impurities such as asphaltic resins must also be taken into account.

(*c*) Carbonisation (the percentage of asphaltene formed) increases much more rapidly than the evaporation loss, both as regards increase of time at a particular temperature and increase of temperature after heating for the same length of time.

The relation between flash-point, fire-test and distillation range of an oil has been discussed, and also the relative value of the carbonisation test and the coke value of an oil as an indication of the value of the oil for the lubrication of internal combustion engines.

In conclusion, I wish to thank Dr. W. F. Faragher for kindly assistance and advice in part of this work.

I am also indebted to Dr. E. W. Dean of the Bureau of Mines for giving me full particulars of the method for the distillation of lubricating oils in a partial vacuum.

DISCUSSION.

(Dr. Ormandy pointed out, during the reading of the paper, that wherever the term "carbonisation" occurred, it did not mean a blackening of the oil, but the formation of resinous or asphaltic bodies.)

Mr. L. Archbutt (Midland Railway Company) said that those present had had the advantage of listening to a most interesting and valuable communication which everyone would study, and personally of which he hoped to take considerable advantage in the laboratory. He felt, at the moment, somewhat like a man who had eaten a very

heavy meal and was suffering from acute indigestion. If time had been given to him to consider the paper before being called upon to speak upon it he would have been in a better position to discuss it. He also felt some diffidence in opening the discussion, because his work did not take him very much in the direction of the examination of oils for internal combustion engines. He had more to do with oils used in saturated steam engines and in superheated steam engines. He occasionally had to test oils for internal combustion engines, and the tests that he had usually made, on the lines referred to in the paper, were to heat a quantity of the oil in a flask for 48 hours to a temperature of about 200° C., and then determine the change in viscosity, the amount of asphalt insoluble in petroleum spirit, and the change in the acidity of the oil. Repeat tests by this method gave fairly concordant results. He had generally been able to trace a very useful relationship between the change in the viscosity and the percentage of asphalt produced. He had not had very much experience in coking tests; he had not used Conradson's test, but another coking test by Gray, which was carried out in a flask. That test was not found of a great deal of use. The results did not agree with the indications of the 48-hour heating test, and concordant results were not obtained in repeat tests on the same oil. He desired, in conclusion to thank Dr. Ormandy for having sent him an invitation to be present at the meeting, and also to express his thanks to the author for his valuable paper.

Mr. E. A. Evans said that he was sure that there were other members who felt very much in the same position as Mr. Archbutt. There was so much material in the paper that, without reading it through very carefully, it was impossible to make fair criticisms.

Many theories had been advanced in connection with the carbonisation of oils, and many of these theories were still upheld, but he was a little curious to know how these theories originated. Some believed that the unsaturated hydrocarbons present in the oil were responsible for the carbonisation, others to the coloured constituents, and others to the material which was absorbable, and so on, but no one seems to have got at the root of the problem. He did not know why chemists should so frequently go for these substances which were regarded as catalysts, without the least idea of the nature of the catalyst nor upon what substances they react. We do know almost definitely that there are a variety of substances which when present in minute quantities are capable of decomposing a large volume of oil, but these are only met under special circumstances. He did not see why we should not go straight for the structure of the hydrocarbons.

Many tests have been made not only by other investigators, but

by himself, with the object of proving or disproving whether the unsaturated hydrocarbons were in any way responsible for the carbonisation, and for his own part he has practically come to the conclusion that they were not. More might be said about the supposed presence of unsaturated bodies in the oil, but no doubt a more opportune moment will arise later.

With regard to resins, he had taken a large number of oils and extracted them with numerous solvents and various absorbents. He had subjected them to the oxidation test, but it had not led to the goal he desired, consequently he was now tackling the problem entirely from a chemical point of view; he was synthesising pure hydrocarbons and testing their carbonisation value. In that way he thought it would be possible to arrive at an affirmative result rather than a negative result as had been done in the past.

There is a reference in the paper to the current belief that there is some relationship of the colour of an oil to its carbonisation value. In the speaker's book, *Lubricating and Allied Oils*, data is given to show that the belief is unsound.

The coke value is held by many workers to be a principal guide in the selection of an oil for internal combustion engines. The wisdom of this belief is yet to be demonstrated. If the temperature of the liquid oil film, as stated in the paper, does not exceed 150° C. it seems unnecessary to heat the oil above this temperature when making a test. The making of a test at a temperature below the coking point appears to have been condemned without a trial, owing to the length of the test, but the following data will show that an oxidation of 45 hours at 150° C. is valuable:—

A . . .	0·3%
B . . .	0·033%
C . . .	0·2%
D . . .	0·05%
E . . .	0·2%

and that heating in an open dish in an air oven at 250° C. for three hours and the material insoluble is petroleum spirit determined, is not quite so sensitive

A . . .	0·12%
B . . .	0·075%
C . . .	0·11%

whilst the coke value reveals little

A . . .	0·79%
D . . .	0·89%
E . . .	0·80%

From engine trials it has been found that oils B and D are superior to A and E.

If a coke test should be found to be useful, the method designed by Ramsbottom is far superior to Conradson's method, and can be recommended to give consistent results.

The table of temperatures quoted are very interesting, but possibly the methods adopted for their determination are more interesting.

The statement that oil goes into the combustion space as a fine spray is not beyond criticism.

Evidently there is a considerable amount of confusion concerning the use of asphaltic and paraffin base oils for internal combustion engines. It is certainly contrary to the generally accepted views that a paraffin base oil of higher viscosity would be chosen than if an asphaltic base oil were used.

Now that engineers are becoming more insistent upon the quality of lubricating oils it behoves chemists to pay more attention to the estimation of asphaltic substances in oils. At the present moment this determination is in a most unsatisfactory state.

Adsorption is a subject of vast importance not only in the oil industry but in numerous other branches of science, and is one which has received a considerable amount of attention. It is reasonably certain that we can learn much from the results already obtained in those other spheres.

It is stated in the paper that it is desirable that a lubricating oil should have a small boiling-point range. Some proof of this is wanted, as it does not appear to be quite in accordance with Hardy's recent work.

In conclusion, one hopes that Mr. Garner is not anticipating the substitution of loss or evaporation for some form of carbonisation test.

Mr. Gordon Pitt said he could not help thinking that if Mr. Archbutt and Mr. Evans were suffering from mental indigestion the majority of those present must feel that they had eaten something they could never fully digest. A number of the members, such as himself, who could not enter as closely into a technical discussion on the actual carbonisation of lubricating oils in internal combustion engines as such authorities as Mr. Archbutt, and such growing authorities as Mr. Evans, had an interest in it a little detached from their membership of the Institution, namely, as users of internal combustion engines. He possessed a motor-car, and the point raised by Mr. Barringer, in connection with the use of petrol in petrol engines, was a very useful one in view of the troubles that arose. In examining a problem of that intricate nature it seemed to him that the investigator who started with preconceived notions based on his own particular speciality

might be deluded into considering that certain conditions which arose in the lubricating oil during its ordinary use might be derived from its own properties, when possibly they were derived from another set of conditions altogether. It was hardly necessary for him to enter into that subject in detail; he simply threw it out as a sort of hint. He would like to hear what Dr. Ormandy felt on the point when he replied. Further, he thought it would be of great interest to find out how Mr. Garner arrived at the various temperatures referred to in the paper. He did not know whether the method was mentioned, but it struck him as being a vitally important thing if some really satisfactory method had been decided upon which would satisfy an investigator as to what the actual temperatures were to which the oils were subjected in the various parts of the engine during use. This was one of the points which make investigations extraordinarily difficult to carry out in the laboratory. It was impossible to get the instruments and apparatus inside the cylinders of the internal combustion engine to investigate what did happen during use, and it had always seemed to him that it was a most difficult matter to lay out the test. If the important question of a really satisfactory determination of the temperatures had been completely settled, it seemed to him to advance the matter very considerably.

Dr. Lessing said he desired to refer to the question of the difference in the amount and kind of the asphaltenes formed from the lighter and heavier oils. He suggested whether there might not be a fallacy in that, because it was possible, if not likely, that the heavier oils might contain the same amount and kind of asphaltenes as the lighter ones after heating or treatment; but that their solubility or solvent power for asphaltenes differed from that of the lighter oils. There were different conditions of mutual solubility in the heavier oils, and therefore it would require different solvents to determine the same kind of material in the various oils. Another point to which he wished to direct attention was the very interesting one of the adsorption of asphaltic bodies by animal charcoal. That was an analogous case to one with which he was more familiar in connection with coal tar. Personally he believed that by studying the differences between the hydrocarbons in coal tar and in petroleum oils it was possible to arrive at a solution of some of these problems. It was a very common thing in coal tar analysis to determine what was called free carbon, but it was never possible to obtain this as pure carbon. It was not known at the present time whether there existed any 100 per cent carbon in coal tar, or whether it was merely a highly polymerised, asphaltic body containing oxygen, sulphur, and certainly hydrogen and some mineral matter. At any rate, it was impossible to get the carbon

absolutely free from bodies containing hydrogen, and it might be that, although a large proportion of the carbon was very similar to the animal charcoal used in the author's tests, just because of its similarity it adsorbed some of the pure hydrocarbons or some of the asphaltic bodies, which could then never be completely extracted. It might be possible to learn from a study of that aspect of coal tar analysis something about the other oils.

Mr. L. Archbutt said that, arising out of what Dr. Lessing had said, he desired to mention that he had occasion some little time ago to make some analyses of Acheson's colloidal graphite, known as "oil-dag." It consisted of colloidal carbon particles mixed with oil, and he found it was quite impossible to wash the whole of the oil away from the carbon particles. After extracting with solvents as much oil as it was possible to get away, the carbon that remained was not all graphite, but contained quite a considerable amount of adsorbed oil. He thought that the lubricating value of those graphite particles might be enhanced in some way by the adsorbed oil. He thought it might be of interest to mention that fact, which was referred to in the *Report of the Lubrication Committee*,* which some of the members might not have read.

Dr. Blackler said it was necessary to carry out some specific work before making any definite statements on the subject with which the paper dealt. During the last four or five years he had had considerable dealings with lubricating oils and had treated them with sulphuric acid in order to produce medicinal petroleum. In dealing with those matters he came across instances which showed the various nature of the oils in relation to the amount of unsaturated bodies contained in the oils from different parts of the world, and the difficulty with which those various oils could or could not be treated with sulphuric acid. For instance, Russian lubricating oils contained 75 per cent of saturated bodies, Californian oils approximately 48 per cent, and Texas oils varied from 55 per cent to 65 per cent. He always wondered what effect those respective percentages of the various bodies could have on their lubricating properties. Merely with that desire he had an Edelenau plant fitted up and he had it in mind to make a series of tests to attempt, by carefully abstracting the various quantities of the unsaturated bodies from those lubricating oils, to get lubricating oils containing various quantities of saturated bodies of known character more or less in order to carry out lubricating tests. Unfortunately he was not able to go far with the matter, but the apparatus was now in hands where that could be done and he was looking forward to the time when those tests would be made. It was his belief that,

* Dept. Sci. and Ind. Research, 1920.

in addition to the resins contained in lubricating oils, which constituted only a small amount, there was a much larger amount of diolefine bodies together with olefines, in addition to the saturated paraffins and napthenes; and they all played a very curious and unknown part in the question of lubrication. It was a very well-known fact that the viscosity of mixed lubricating oils was not directly proportional to the viscosity of the constituents, yet the strange part about it was that if saturated lubricating oils (medicinal petroleums) were mixed one could industrially determine the viscosity of the mixture as proportional to the percentages of the two constituents. These questions are worthy of very serious consideration, and they were in his opinion the lines on which work must be done if definite knowledge was to be obtained on the factors underlying the utility of various petroleum oils for lubricating purposes.

Mr. A. E. Parnacott said he had been hoping that some engineer would have joined in the discussion and thrown some light on the subject of the internal combustion engine and the carbonising trouble in cylinders. In the first place he desired to say it was accelerated by the circulation of oil in the crank chamber. The black condition of the oil soon became apparent after a day or two's use, and he thought that must accelerate the carbon deposit in the cylinder. Personally he did not believe in the circulatory systems.

The piston rings played a very important part in the carbonising up of the cylinders. He had been concerned in some tests, and standard piston rings which were bought were found after a time to be slightly conical on the outside. When the rings were put in so that the larger diameter was at the head of the cylinder, it was found there was more carbon deposit in the cylinder than in cylinders in which the piston ring was the other way round. He then searched the Patent Office with the object of seeing whether there was any chance of getting a patent for piston rings in which the sharp edge of the piston ring was towards the crank chamber and the rounded edge was towards the combustion chamber, with the idea that the piston rings should ride on the oil film in one direction and scrape off in the other. Such proportioning of rings was not novel.

He desired to ask the author whether he could give any information on the question of the absorption of the fuel oil by the lubricating oil. As fuels were getting heavier he thought there was a greater tendency for them to get into the lubricating oil, a point about which he knew the author was fully aware. He suggested that a way out of the difficulty would be to have a type of engine with the crank shaft above the cylinder. The more rapid carbonisation in cylinders was, he thought, largely due to the more general use of the throttle at the

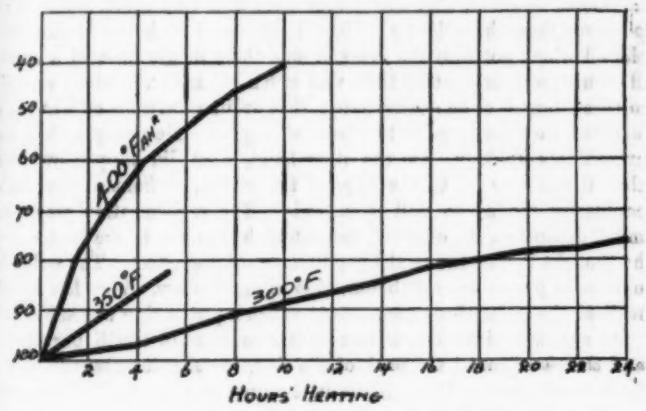
present time—he was referring more particularly to road vehicles. Cars were now designed with such low gears, in order to avoid the use of a gear box, that the compression pressure in the cylinder was materially less; the temperature in the cylinder was, he understood, also less; so that the lubricating oil which got by the piston ring was not so readily burned. The larger suction effect would also cause a larger quantity of lubricating oil to get by the piston rings. He remembered that some years ago considerable trouble was experienced with a certain engine made by a particular manufacturer, which would run perhaps 1000 or 2000 miles and then have to be decarbonised. He was called in by a private owner to examine the engines and very quickly saw what was wrong. He suggested that much stronger valve springs should be fitted to the exhaust valves. That was done, and he subsequently heard from the owner that the car had run 5000 miles and he did not think the engine would ever want decarbonising. He did not know whether Dr. Ormandy would throw any light on that point.

Dr. W. R. Ormandy, in reply, said he was not going to pretend to take the place of the author of the paper, but he desired to take the opportunity, in endeavouring to reply to the discussion, to say a few words as a deputy for the author. Mr. Archbutt had said that he preferred to heat his oils for 48 hours at 200° C., using a considerable bulk, but if they were contained in a flask the oxidising action was very considerably reduced. In Mr. Garner's experiments every effort was made to expose a large surface in order to get the resinification brought about as rapidly as possible. Personally he had tried the heating of very inconsiderable bulks of oil over varying periods, and the results of the experiments were recorded in the *Journal of the Institution of Automobile Engineers.* He then tried the effect of heating the same oil in a flask that was practically filled, and the results were entirely different, showing that it really was a case of the action of air. Mr. Archbutt made a very interesting remark about oil-dag, the carbon, which was really graphite in that case, retaining something of the nature of oil. If it could not be extracted by means of any extracting medium, he did not know how Mr. Archbutt knew it was oil. It might have some of the properties of oil, but personally he suggested it was quite possible that the graphite was acting just as animal charcoal did and was adsorbing certain specific contents of the oil which were irreversibly held back by the graphite and which no solvent tried was capable of removing. He merely put that forward as a suggestion. Mr. Archbutt also said he did not find the coke test very useful. So far as the Diesel engine was concerned, the coke test was not only useful but absolutely vital.

So much importance was attached to the test that the Diesel Engine Users' Association in this country had a specific test not only for the lubricating oils, but for the fuel oils as well. A great deal of attention had also been paid to the subject by the German Tar Distillers Federation (Deutsche Teer Produkten Vereinigung) in relation to gas tar for Diesel type engines. Although there the oil got into the engine, in one case by accident and in the other case deliberately, one being put in with the intention of being burned and the other being put in in order to lubricate, in both cases it was equally vital that the oil getting in should not be converted into coke, and therefore the coking value was very important. Moore recommends that the methods used in the laboratory of the Royal School of Mines should be used for the estimation of the coking value. Of 100 cc. of oil they distilled off what came over up to 300° C., and the remainder of the oil left over from the distillation of the 100 cc. was removed for the determination of the coking value, a reasonably weighable amount, which was necessary where the coking value was placed at a very low limit, thus being obtained. Mr. Evans had introduced the question of theory and had asked why they should not go for the structure of the hydrocarbon at once. Personally he thought it was most essential and desirable that that work should be done. At present they were working entirely empirically and very much in the dark. The expense of building up a lot of pure hydrocarbons in quantities necessary for that sort of work was very considerable, and their separation from existing oils was practically impossible. He thought they must be synthetically made. They certainly did require that a large range of synthetic hydrocarbons should be made, and that they should be able to get their physical contents accurately and use those as a basis to go upon. The very interesting point raised by Dr. Blackler had an immediate bearing on that subject. It was well known that certain oils, particularly the asphaltic base oils, did not have a viscosity which was the mean of the ingredients that were mixed. If, as Dr. Blackler said, the pure saturated hydrocarbons from which, either by SO_2 or sulphuric acid or otherwise, the unsaturated portions had been removed, really had properties which in that respect were the mean of their constituents, that was a step in the right direction; it constituted some fundamental basis to work upon. Mr. Evans also said he did not like the coke test and that it had not given very good results. According to the author of the paper, however, the coke test was the main one which gave valuable figures in relation to the production of carbon in the internal combustion engine. He presumed that Mr. Evans heated for a considerable time at 150° C. rather than for a short time at 200° C. Unfortunately the lantern was not working.

but he had prepared some slides showing the comparative results of heat action for various times at 300–350 and 400° F. on a high-grade oil with closed flash point of 473° F.

It would be noticed that the difference was very great. A variation of 100° F. enabled one to do in 4 hours what it took 24 hours to do at 100° lower temperature. Mr. Evans also referred to the fact that the cylinder walls were only at an approximate temperature of 150°. The figures of temperatures given in the *Report* were not all made by the author, who, however, gave the necessary references to the authorities from which they could be obtained. They were made by Callender, Beilby, Hopkinson, and others. They were very difficult



EFFECT OF TEMPERATURE AND TIME ON HEAT LOSS.

to determine, but a great deal of work had been done upon them. As a matter of fact, temperatures differed with the conditions, the number of revolutions, and the type of carburetter employed. He had seen a Sunbeam racing engine being tested to destruction. The piston at the end of about half an hour's running was partly caved in and so discoloured that it was obvious that it had been at a bright red heat, and the exhaust valve stem showed red below the bottom of the guide. Under those conditions lubrication was quite a problem! There was no doubt, however, that the cylinder walls were not at a high temperature, but it was very unfortunate that it was impossible to get the oil in the engine to stop on the cylinder walls. The trouble was introduced on the suction stroke. The modern tendency to use high speed engines with high piston speed running for a large part of their work under a very much closed throttle led to the very low

pressures in the cylinder and consequent carbonisation. He thought there was a good deal in the point raised by Mr. Parnicott. Just before the war carbonisation in cylinders was a fearful nuisance. He had an engine which he never could run for more than 1500 miles without having to scrape out a lot of dirt. It led to pre-ignition and it was impossible to run on an open throttle. That was because in those days there was a number of gears and drivers were not afraid of using them. Makers at the present time tried to build an engine that would go up Mont Blanc without changing gear, with the result that nine-tenths of its time it was running at a very low speed and the temperatures throughout were comparatively low. There was no doubt, however, that the pistons were at a very much higher temperature than the cylinder. He did not agree with the author that the oil which got into the cylinder was there in the form of a spray. He could not conceive that there was such a leakage, even with a vacuum of three-fourths of an atmosphere; that ordinary viscous oil was being squirted past the rings in the form of a spray. He thought that was exceedingly unlikely. On the other hand, what did happen was that the oil got over on to the edge of the piston, carbonised there and capillarity tended to pull it inwards. The carbonisation was very much greater on the edges of the piston than it was in the centre, and he thought it was due to the capillarity creeping effect. The ordinary motor-car piston was an abomination in many ways. Very few people realised the tremendous pressures to which a piston ring was subjected.

At one part of the stroke there was a pressure of 300 lb. per sq. in. and the gases got at the back of the ring, pressing it outwards with a force much greater than the natural spring of the ring. There were means of getting over that trouble in a steam engine where weight was not important, but if he attempted to discuss that he would be going away from the subject of the paper. He thought the oil got into the cylinder on to the top of the piston, at any rate, chiefly by crawling off the walls, and it then spread by capillarity. The author pointed out that the carbon was not pure carbon; it was a mixture of asphaltene, oil, and pure carbonaceous matter. Dr. Lessing had pointed out that the so-called carbon in tar was not carbon, but that it always contained hydrocarbon. It was possible to go a lot further than Dr. Lessing had done with regard to the carbon on the top of a cylinder. The bulk of it, so far as his tests went, consisted to the extent of up to 60 per cent of unburnable material, road dust, and, strangely enough, it almost invariably contained not only copper, which one would expect from the brasses and so on, but, in a number of cases in which analyses had been made, of an unusual amount of zinc. It was by no means carbon. It was generally arranged that a

car made as much dust as possible; one car ran behind another. The dust went in through the radiator with a nice fan to suck it in; it then entered the induction pipe, where there was still a greater velocity, and went into the cylinder; and it would be unreasonable to expect that when the dust got into a cylinder with nice greasy walls it would not reside there, and it did. The statement that Dr. Lessing had made that the carbon in coal tar was not carbon was quite correct. It was really highly polymerised hydrocarbons of an enormous molecular weight. An interesting experiment had been carried out by W. Feld in his plant for fractional condensation of the gases from the distillation of coal, where, instead of cooling the whole lot into a sticky tar and then distilling off the oils to recover the pitch then condensed it, lowering the temperature, so that only the heavy tars were condensed in the first unit. That tar contained practically no measurable quantity of so-called tar carbon. It was entirely soluble in benzol and left no appreciable amount of residue. If that thick tar were heated in a porcelain basin up to a temperature of 250 or 300° C., and then allowed to cool, anything from 5 to 20 per cent of material insoluble in benzol was obtained, showing that a tar which was condensed out of gases under those conditions, not having been subjected to any higher temperature than that at which it was produced, was an exceedingly unstable body, which, when subjected to comparatively low temperature in a pure state, polymerised to a very considerable degree and became insoluble. Mr. Barringer asked whether the whole deposit was due to lubricating oil. He thought he had already answered that question to a very large extent by saying it was due to the road dirt. Having regard to the type of petrol that had been commonly employed during and, to some extent, since the war, he thought there was very little doubt that the bad carburation and the formation of a certain amount of carbonaceous matter were due to the fuel employed. Mr. Parnicott had asked a question with regard to the adsorption of fuel in the oil. He thought there was very little doubt that the fuel got past the ring downwards just as readily as the oil got past the ring upwards. The crank case was an ideal oil washer. On any gas charged with petrol or paraffin the crank case acted as an excellent washer and adsorbed fuel until there was an equilibrium vapour tension at whatever temperature the crank case happened to be. When during the war the taxicabs of London were instructed to save petrol by using a mixture of certain parts of paraffin and petrol, they obeyed; they could buy paraffin and they could not get petrol, and that enabled them to stop on the roads, but the mortality in big ends was something absolutely unprecedented. What happened was that whereas, even with commercial war petrol, possibly

not more than 3 or 4 per cent was adsorbed by the lubricating oi when the vapour tension equilibrium was reached, it was possible t get paraffin into the lubricating oil and it did not raise the vapou tension enough to get distilled out. The result was that as the lubri cating oil got thinner and thinner it was no longer a lubricant, an the big end or the gudgeon pins went. That was one of the trouble experienced when using those heavy fuels. America suffered very largely from lubrication difficulties which were not met with in thi country, because the average fuel which the American had to use in his motor-car engine was something which was incomparably worse than the fuel used in this country, however much the people here might grumble about it. He did not think more than 10 per cent of the engines built in this country would run reasonably well and economically upon American fuel. When the day arrived when they had to use a fuel which, instead of finishing boiling at 160 or 180° C., finished at 240 to 260° C., it would be found that beautifully clean cylinders with the induction pipes cast into the cylinders were of no earthly use ; they would be required outside, where they could be kept hot. He desired, in conclusion, to express his regret that the author was not able to be present to give particulars of many interesting things that he must have discovered in carrying out his investigations.

The meeting then terminated.

Mr. F. H. Garner's reply to the discussion will appear in Journal No. 27.

IV.

BIBLIOGRAPHY.

This includes all the more important references dealing with evaporation and carbonisation of mineral lubricating oils and with the lubrication of internal combustion engines. The references are by subject and for each subject are in chronological order.

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3. A. Duckham—B. Redwood—Treatise on Petroleum, 1913, ii., 271—heats 2 gms. of oil in glass beaker for four hours at 300° C. on slowly rotating shelf in gas-heated oven.

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Carbonisation Tests.

(See also Evaporation Tests.)

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(See also Nos. 8, 32, 33, 56a, 89, and under Carbon Test.)

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Third Annual Dinner.

The Third Annual Dinner of the Institution of Petroleum Technologists was held at the Connaught Rooms on Thursday evening, 17th March, 1921. Sir Frederick Black, K.C.B., the President, presided over a gathering which numbered nearly 200, among the principal guests being Brig.-Gen. R. K. Bagnall-Wild, C.M.G., C.B.E., Sir Robert Waley Cohen, K.B.E., Mr. J. A. Corcoran, C.B., Mr. G. E. A. Grindle, C.B., C.M.G., Mr. James Hamilton, Viscount Hardinge, C.B., Mr. W. St. D. Jenkins, C.B.E., Mr. Stanley Machin, Mr. C. O. Milton, Mr. J. W. L. Oliver, C.B.E., Mr. F. E. Powell, Sir John D. Rees, Bart., K.C.S.I., C.V.O., M.P., Colonel R. D. Temple, D.S.O., and Sir Capel Wolseley, Bart. The Members of Council present were: Mr. Herbert Barringer (Vice-President), Professor J. S. S. Brame (President-Elect), Professor Sir John Cadman (Past President), Mr. Arthur W. Eastlake (Vice-President and Honorary Secretary), Mr. James Kewley, Dr. W. R. Ormandy, Mr. T. C. Palmer and Dr. F. Mollwo Perkin. It was announced that communications regretting their inability to attend had been received from Mr. F. G. Kellaway, M.P. (Parliamentary Head of the Petroleum Department), General Sir Capel Holden, Mr. W. C. Bridgeman (Parliamentary Secretary to the Board of Trade), Sir Richard Gregory, General Sir Travers Clarke, Sir William Plender, Rear-Admiral the Hon. Algernon Boyle (Fourth Sea Lord), Sir Henry Fowler, Sir Hugh Barnes, Mr. W. C. Sneath (Price, Waterhouse and Co.) and Sir Charles Greenway, Bart. (Past President).

The Toast of "The King," which was proposed by the President, was accorded musical honours.

"The Services."

Sir John D. Rees, K.C.S.I., C.V.O., M.P., in proposing the Toast of "The Services," said he wondered how it was that being neither a soldier, a sailor, an airman nor a petroleum technologist the honour had been accorded to him of proposing the Toast. He remembered, however, a well-known lawsuit which was heard when he was a young man, when Mr. Whistler, the painter, brought an action against Mr. Ruskin, the writer, for libel because Mr. Ruskin described Mr. Whistler as a coxcomb who threw a pot of paint in the public's face and charged anything from £100 to £1,000 for it. When Mr. Ruskin was asked whether he could paint he said he could not, but that he had spent his life among paintings, to which Mr. Whistler retorted: "So has the policeman in the National Gallery." He felt a certain amount of comfort, therefore, when he reflected that he had spent a great deal

of his life amongst soldiers, whom everyone admired and respected, and to whose courage it was due that the members of the Institution were able to dine in comfort and security on the present occasion. He had also made many voyages between England and India and around the world, and everywhere he went there was a great battleship or a British merchantman close at hand. The security of the country, therefore, and of its citizens was due not only to the Army, but to the Navy, and to both of them in happy conjunction. As the supporter of a Government which was abolishing four cavalry regiments, he felt a certain amount of shyness in proposing the Toast. He was somewhat encouraged when he remembered that for years he was the Whip of a little party in the House of Commons which objected to the reduction of the Army, and the Minister in those days who was responsible for the reductions, who was really a great benefactor of the Army, had always been accused ever since of being unfriendly to it because he was the means of reducing it. He could not help feeling gratified that an announcement had recently been made that the Government was not going to give up, at any rate for the present, the building of big battleships, which he confessed gave him an enormous sense of comfort and satisfaction when he looked upon them. There must be a good deal to be said on both sides for and against big battleships, but personally he was glad that the Government had decided not immediately to forsake the building of battleships for other craft above and below water. He desired to say a word with regard to the eminent soldiers who had left the Army and the Navy to take part in civil pursuits not remotely unconnected with the Institution of Petroleum Technologists. While objection was taken recently in Parliament to the fact that a capable administrator had left Government service for the purpose of going into the service of one of the great oil companies, he thought it must be remembered that trade and commerce were as great factors in the life and the prosperity of the nation even as the Army and the Navy. "Once a soldier always a soldier" and "once a sailor always a sailor" was, he thought, a narrow view to take, and certainly nobody would suggest that once a man was an airman he should always remain up in the air. Personally he would very much regret if the field that was open to a capable man was restricted in the manner that had been suggested. It must also not be forgotten that without the activities of the great commercial institutions which produced oil the Allies could not have won the war. If the best brains of the country had not been concerned in the production, the refining and the distribution of that all-necessary product for all the Armies of the Crown, victory would not have been achieved. He remembered when travelling in Russia, seeing the oil wells spouting

at Baku. There was a silence for a moment while the great subterranean forces seemed to be gathering together; it was a kind of silence that could be felt and almost heard; and then the oil suddenly burst forth like a genii which had been imprisoned in a bottle. The oil spouted out with enormous noise, giving an impression of great power, and that crude oil was then distributed all over the world. From that day he had always felt how important an Institution must be which dealt with petroleum, and how indebted the Army, the Navy and the Air Force must be to it for the raw material with which they fought and vanquished their enemies.

Brig.-Gen. R. K. Bagnall-Wild, C.M.G., C.B.E., in responding, said the Services knew very little about the House of Commons. All they knew was that they were constantly asking for a lot of money, and some vague sort of people, called the Treasury, immediately said they could not have more than half the quantity desired. The Services, however, hopefully went on asking for more, and sincerely trusted that the taxpayer would be able to bear the burden. The men in the Services were enthusiasts; they liked their job, and they wanted the very best means placed at their power with which to provide the protection to which Sir John Rees had referred. It was all very well to have soldiers, sailors and pilots, but they were of very little use without fuel. There were many people in the Services who realized the value of fuel and where it could be obtained, but the average pilot, motor-car driver, Army Service Corps officer and engineer of a ship did not care twopence where the fuel came from so long as it was good and gave him little trouble. But those who had to supply the article realized that point of view very strongly, and he was very glad to say that, so far as the Air Service was concerned, it was getting very closely into touch with the Institution, because it fully realized the benefits to be obtained therefrom. It had recently obtained some very good advice from the Institution with regard to lubricating oils and fuel for aeroplanes. The fuel for aeroplanes was a very interesting problem. In the average motor-car the specific gravity of the fuel did not matter very much, but in regard to aircraft putting up the sp. gr. from 720 to 766 was a very important matter indeed, because considerable weight had been added which had to be lifted, and the radius of action was consequently reduced. That trouble had been overcome by increasing the value of the fuel; in other words more horse-power were obtained per volume, so that it was possible to carry the increased weight. A good deal more remained to be done on the subject, however, and the Air Force was trusting to the Institution very largely to help them in that very difficult problem. At the present moment the problem was divided into two

parts. In the first place a fuel was required for the existing engines in which the compression ratio was about 5·5 to 1; but there was no reason in the world why compression ratios of over 8 to 1 should not be used if the proper fuel were supplied.

"THE INSTITUTION OF PETROLEUM TECHNOLOGISTS."

Mr. F. E. Powell (Chairman of the Anglo-American Oil Co.) said it afforded him very much pleasure to propose the health of the Institution of Petroleum Technologists, coupled with the name of its President, Sir Frederick Black. He desired, in the first place, to refer for a moment to the gentleman who was instrumental in founding the Institution, the late Sir Boverton Redwood, who was a great personal friend and whom he always esteemed as a man of science and of sound business principles. The industry which those present at the gathering represented never needed scientific development more than at the present time. The refiners and chemists dealing with their product had done their part, but the whole world was crying out for oil for fuel, for lubricating purposes, for motor transport, and for many other uses with which everyone was familiar. America had eight million more motor-cars than all the rest of the world combined, and the cry was ever for more and more oil. Technologists and geologists were searching for it all over the globe—in Mexico, in the Philippines, in Venezuela, in Papua and elsewhere, including Yap, a place he would not refer to as it was mixed up with a little trouble. In the search for oil in different parts of the world men underwent great hardships. What a great thing it would be if it were only possible to have oil here at home! How much more comfortable it would be if there were oil in England! As yet no concessions had been granted for finding oil in England; the furthest they had been able to get Sir John Cadman to go was to issue a couple of licences. If oil could be produced in England it would not have to be transported from overseas, and many benefits and conveniences would result. For instance, it would be unnecessary for petroleum geologists to live in the beastly climate of Persia; they would not have to dwell in the jungles of Venezuela; and they would not have to suffer from the unsatiable thirst of California. Personally, he was a believer in an oil *entente*. He thought the best minds in this country and the rest of the world, including America, should be devoted to a combined effort for the purpose of finding supplies of the precious product with which they dealt. Nobody ever found America backward in giving of what she possessed. She was always ready to give advice, and her opinion on prohibition was well known. People in America had recently been devoting them-

selves a good deal to some invidious comparisons of two prominent scientists in connection with oil, namely, Mr. Ralph Arnold, of the American Institute of Mining and Metallurgy, and Dr. White, of the United States Geological Survey. Dr. White said that the world had only 43,000,000,000 barrels of oil left in it—he believed the exact figure was 43,055,000,000. He did not know where Dr. White got the odd 55,000,000 from; he thought he must have been talking to Sir John Cadman about it. Anyway, that was all the oil there was. Mr. Ralph Arnold said that the United States at its present rate of consumption would use all that oil in the next eighty years. The scientists connected with the Institution of Petroleum Technologists had got to get busy. He would like to know what they were going to do about it. They had only got eighty years, and then if they did not do something there would be no more oil and the Institution would go smash. Big business was a very great romance. Shakespeare said in *Hamlet*, "There are more things in heaven and earth, Horatio, than are dreamed of in your philosophy." He did not think men connected with oil had much chance about the things that were in heaven, but the petroleum scientists had got to get busy about the things that were in the earth. Personally he believed in team work. Team work did not mean that there was only one star performer. Everybody had to pull together, and big business was based on the lines of co-operation in exploitation, development and organization. The scientific and technical men came right in with the rest, and they were a very important part. The Institution was built up for the purpose of enabling those men and their friends to get together and inspire other men of the same nature all over the world to work together towards the one great end of developing the petroleum products of the world. The Institution had a very wide and important future before it, and he believed that in the work it had undertaken it would develop the industry along sound rational lines, and keep those who were in charge of the direction of the industry well informed. He, therefore, felt impelled to say that, with a body of enthusiastic, trained, scientific men there could not be anything but a wonderfully brilliant future for the Institution, and he called upon everyone to drink its health.

The Toast was enthusiastically honoured.

The President, who was received with cheers on rising to respond, said that his name had been on the programme of the three Annual Dinners of the Institution, and through his association with the organization of those programmes he had learned to have a very great admiration for their friend, Mr. Ashley Carter, for all the hard work he did in making them such a success. He had, however, never admired

Mr. Ashley Carter's artistic skill more than he did on the present occasion, when he had very skilfully arranged that a song should be sung between each of the speeches. Those present would have noticed that, when it came to a question of a speech by an American gentleman to be followed by a speech by a humble Britisher, Mr. Ashley Carter carefully arranged that two songs should be sung between the speeches. That simply emphasized the fact that there must be a double dose of harmony between the representatives of America and of this country. He was very glad to know that that harmony existed, and he trusted it would always be the case. Some little time ago Mr. Powell asked him to say a few words on the occasion of a luncheon he gave in honour of Mr. A. C. Bedford, head of the War Services Committee in America, with whom he had worked hand-in-hand during the war. He tried then to say a few words on the value of frankness, which was a great virtue not only of Americans, but of Britishers. Whenever Mr. Bedford in America thought that he could handle the oil supplies of the British Navy, or the Allied Navies, or the Armies better than the recognized authorities could do he used to come and say so; and whenever he (the President) had a particularly bad attack of swelled head, and had not got his measuring tape handy, he used to go and tell Mr. Bedford how much better he could handle the affairs of the Americans than the War Services Committee or even the Standard Oil Company. He was recently saying something of the same kind to an American friend, who replied, "Well, why not? In America a man from Louisana can always call a fellow from Texas an asinine specimen or any other name he likes, but he has always got to do it with a smile and convince the other fellow of the honesty of his intentions." A speaker from America on oil matters was always very interesting, and there was no man who could speak more interestingly on that subject than Mr. Powell had done. Mr. Powell had referred to the possibility of oil lasting another eighty years, but personally he desired to refer to another aspect of the question that had not been touched upon. When he was recently in America a very old friend of his, Mr. Mark Requa, was talking to him about the question of co-operation in the exploitation of oil. He listened carefully to what he said, and when he had finished, replied: "There is one thing we ought to co-operate in, and that is in the economical use of oil." Mr. Mark Requa looked out of the window with a sort of far-away look in his eyes, and did not seem particularly interested; but he (the President) noticed recently in an English newspaper some extracts from an address that Mr. Mark Requa had delivered in America, in the forefront of which was a comparison between the expenditure of oil products per head in America and in Great Britain. Mr. Mark Requa put the figure rather higher than he

would have done; he said it was 20 to 1, although personally he thought it was nearer 8 or 10 to 1. If co-operative means could be employed to obtain a more economical use of oil, the period of eighty years which Mr. Powell mentioned might perhaps be extended to 120 or 180 years; and if that were the case it would give time for the diplomatists to work out a settlement of some of the questions on which they were at present engaged. It would also give time to the members of the Institution to get on with some of the new activities that they were so keen about at the present time. He desired to mention a few of the new activities of the Institution. Some genius on the Council discovered that in ancient Rome the great Imperial Government did not hesitate to set apart a day once a year for suggestions from its subjects as to how the great Empire might be better governed. The Institution adopted the principle, and at an informal meeting recently held a number of admirable speeches were made, each of which were full of good suggestions for new activities. Amongst the very first mentioned was closer co-operation between the scientific and technical people of this country and of the United States, and a good deal was being done to bring that about. Another member stated that the people who blundered most in petroleum subjects were those from whom light and leading ought to be obtained, namely the Ministers of the Crown and Members of Parliament. He suggested as a remedy for that state of affairs whether all public men should not be put through a mild course of petroleum technology. The suggestion had been referred to a Committee, which had already presented an interim report, but he was still waiting for the final report which would deal with the great subject of how that education in petroleum technology was to be given to public men. Some public men would be inclined to say: "Is this some new terror that is to be added to public life." Having sat in the President's Chair for two years and listened to about twenty lectures and twenty discussions on petroleum technology, he could assure public men that the subject was dealt with so delightfully that it was a pleasure and not in any way a terror to be instructed in petroleum technology as it was carried out under the auspices of the Institution. Other suggestions that were made related to standardization and nomenclature, most important subjects which should receive early attention, as different words were used not only in this, but in other countries to mean the same thing. Then there was the question of the standardization of tests and the measurement of various things. Every country liked to have its own instrument and methods of measurement. People in this country liked the Redwood; the Germans liked the Engler; and so far as the flash point of oil was concerned, as each inventor

produced a new method so he added his name to it. A combination was required of the names of the different methods. For certain purposes the world was divided into Ethiopians, Caucasians and Mongolians, but in the Institution no distinctions were recognized, whether men were geologists, drillers, fieldmen, refiners, connected with transport or commercial people. It was known from the newspapers that the oil world commercially was divided into various undertakings. Everyone had heard of the Anglo-American Oil Company, of the Royal Dutch Shell Company, of the Asiatic Company, and he was not sure he had not seen something in the newspapers about a concern called the Anglo-Persian Oil Company. But inside the Institution those distinctions were not made, and everyone, whether scientific, technical or commercial men, combined together with the object of adding to the stock of common knowledge. There were many men who had been in different parts of the world who had geological or chemical knowledge of oil, and it was hoped that they would write papers for the benefit of the industry in order that all might co-operate on one broad platform of scientific and technical training. In the two years that had elapsed since the war, the Institution had doubled its membership from 200 to 400. Of the eight papers that had been read in the current session, two had been written by American citizens and one by a Frenchman. The latter described a process which many had thought was impossible. It had been supposed that to get oil from the bowels of the earth it was necessary to put a drill down and trust to the gas forcing the oil up. Their French colleague, however, informed them that it could be done on the same principle as coal-mining, by making a shaft and galleries, by bringing the oil sand to the surface and washing the oil out with hot water. It could also be done by actually squeezing the oil out of the sand in the galleries underground. There were no end to the possibilities of science in connection with oil production and in the utilization of oil. The question of the economical utilization of oil was as important a matter as the actual winning of oil or its refining, and the last word had not been heard by any means on that subject. He was sure all the members desired to express their very great indebtedness to Mr. Powell for the bright, interesting and frank speech he had made. It was a matter of great pride to himself that he had Mr. Powell on his right hand and Sir Robert Waley Cohen on his left hand, because if there was one thing he had striven for, in the interest of the Institution, in conjunction with his colleagues, it was that it did not lean in any particular commercial direction. The Institution opened its arms to receive all the help it could from every technical, scientific and commercial man who had anything to say on the subject of petroleum.

"Our Guests."

Sir John Cadman, K.C.M.G., D.Sc., in proposing the Toast of "Our Guests," said the Institution was a young body which was striving by various means to stimulate scientific lines of thought in the members of the profession connected with the great industry with which it dealt. Anything in the nature of commercial rivalry had disappeared from the Institution. Commercial rivalry in commerce was a great stimulus to the nations, but if the commercial spirit entered into the deliberations of such an Institution as theirs it tended to remove the usefulness which it might otherwise be to the community. It was a great thing to get together on to a common platform people from all parts of the earth to discuss the scientific aspects of a great industry. The industry was undergoing a process of evolution. It was growing from small beginnings into an industry of large dimensions of which in the future everyone would be proud. It was a great privilege and pleasure to the Institution that distinguished members of the great oil companies and of the great Government Departments had accepted invitations to attend. All the members were delighted to see Mr. Powell, and welcomed him with all heartiness; he had stimulated the Institution to activities which he hoped it would live up to. He ventured to think that the Institution and the sister Institution in the United States would be able to show to Mr. Powell that all the calculations to which he had referred were very inaccurate, because over 60 per cent of the world's surface contained rocks of a suitable age for containing petroleum, and nobody would suggest for one moment that that huge amount of the world's surface had been thoroughly exploited for petroleum. In view of that fact he thought everyone could sleep soundly in their beds, realizing that there were still opportunities for petroleum technologists to make great discoveries in the future. The experience he had obtained in official circles during the war had led him to admire immensely the masters of the petroleum world for the loyal manner in which they devoted their energies to the cause of the Allies. Mr. Powell crossed the Atlantic numberless times in the interest of the Allies; his services were given freely, and he never failed to attend a Conference when vital questions were under discussion, remaining at the same time continually at the wheel of the great industry of which he was a member. He desired at the same time to couple with Mr. Powell's name that of his distinguished associate, Mr. James Hamilton. Reference had been made to the number of licences which his Department had issued for the purpose of testing the oil-bearing possibilities of the territory of this country. He believed that Sir John Rees was the only Member

of Parliament present, and he might remember that the House of Commons confined the activities of the Petroleum Department within very narrow limits. Sir John Rees, as the only Member present, was the culprit, and if anyone was to be shot at for what had been done he was the individual who should be attacked. General Bagnall-Wild was one of the users of the commodity supplied by the members, and who, as a matter of fact, extracted the most exacting fraction of it. As a matter of fact, petroleum technologists could teach General Wild a lot. He also welcomed Mr. Jenkins, the Director of Contracts at the Admiralty, and Mr. Oliver, and he ventured to hope that the activities of that Department might long keep big capital ships in operation for the sake of the petroleum industry. He also welcomed the Director of Contracts at the War Office, Mr. Corcoran and Mr. Grindle, to the latter of whom probably some of those present were saying in quiet voices: "What about Mesopotamia?" The members had the satisfaction of knowing that that particular problem was in safe keeping in the hands of the Department of which Mr. Grindle was the distinguished head. It was a great pleasure to the members that representatives of the Coal Mines Department were present in the person of Mr. Coates and Mr. Cole. The Minister and other representatives who would have been present were unfortunately detained in another place arranging for the decontrol of coal. He was sure the members would also extend a very hearty welcome to Prof. Madgwick, who had taken up the duties of Professor of Petroleum Technology at Birmingham, and Mr. Spencer, the drilling instructor in charge of the drilling operations which were now going on. The petroleum industry was going ahead at a tremendous pace, the output for 1920 having approached something like 97,000,000 tons, compared with 49,000,000 tons in 1912, so that in less than ten years the output had practically doubled. That was a great tribute to those who were responsible for the conduct of the industry. On that particular point he felt it imperative to refer to a wave of feeling which passed through the country at a period when the shortage of petroleum was very acute, immediately after the war. The war had brought about an increased use of the commodity in every direction; it had put on the clock for twenty or twenty-five years, and it was not unnatural that the petroleum industry, in view of the fact that its mind had been so occupied with the war, the difficulties of getting plant and materials and providing transport, was found quivering and unable to meet those demands. At that particular moment certain people found it necessary to make a recommendation that the only way to save the peoples of Europe and to give them their rations of petroleum was to introduce some form of control, while the Government Department

which was responsible for petroleum was with all the force in its power trying to hand the industry to the people who were running it. Nevertheless, a great deal of pressure was exerted to put the clock back by instituting some form of control. At the time the only person who stood out against the suggestion and who took a very determined attitude with the endeavour to keep the industry going on its own was Mr. Clarke, who took a course which he ventured to think would in time be proved to be a perfectly sound one to enable this country and Europe to get adequate supplies; indeed the wisdom of the course was already being shown by the very rapid increases in production, particularly in the United States and Mexico. The members were also delighted to see Mr. Ross, the Managing Director of the Distilleries, and Sir Robert Waley Cohen, with whose name it was his pleasure and duty to couple the Toast. Personally he was in a unique position to speak of the colossal services which had been rendered by Sir Robert to the industry, particularly during the war. He said without any hesitation that he knew of no one who put his back into the work with greater vigour and enthusiasm than Sir Robert. He had seen Sir Robert in the morning, he had heard of him being in France in the middle of the day, and he had seen him back again in England the same afternoon. It was not everybody in those early days who would venture to put his neck in the noose of an aeroplane, even although General Bagnall-Wild was responsible for part of the service. He would not like to estimate the number of times that Sir Robert went backwards and forwards to France in the services of the country in order to make sure that the supplies of the Army were being properly attended to at a very critical period of the war. There was one period when the Army had barely a fortnight's supply; indeed at that period the Army was unable to manœuvre or to go forward. The supplies were distributed unevenly about the zone, and if it had not been for the activities of Sir Robert at that particular moment he shuddered to think what might have happened. The country owed a very great debt of gratitude to Sir Robert for his energy during that particular period.

The Toast was enthusiastically honoured.

Sir Robert Waley Cohen, K.B.E., in responding, said he thought the most striking note that had been struck that evening, and one which he hoped would reverberate throughout the petroleum world for a long time to come, was that of co-operation. He sat at a Board during the war which was called a Pool Board, which rather resembled the fight between two Irishmen which was going on in a public-house, when another Irishman came along and said: "Is this a private fight or can anybody join in?" Everyone joined in it, and they did

so with great gusto. The result was not entirely effective. He did not know that the vigorous controversies and the vigorous competition with which the industry had been faced in the past had done it any harm, but from every direction it had become clear that they could not afford any longer to waste their energies in hampering and fighting one another, and that there was enough room for all and enough for every one to do if they were to cope with the growing needs of the world for the commodity with which it was their duty to supply it. The first work must lie with the technologists, and he for one felt quite sure that they would not let the commercial people down. He was not at all a believer in the prophecies as to the rapid exhaustion as to the world's resources of petroleum. One of the dangers from which scientific men suffered (and he thought the Germans particularly suffered from it in the past) was that of building too heavy a structure upon data which appeared large, but which were not by any means all-embracing. He thought that the man who presumed to judge at the present day as to the oil resources of the world was like a man who could not understand why, when they were living on something that was not relatively thicker than an egg-shell, they did not fall in. When it was realized that out of the inside of the egg some 200,000 tons of liquid were being extracted every day, he thought the fact must come home to everyone that not anything like enough was known of the forces that were governing the world to enable a prophecy to be made as to the amount of liquid which would come out of the earth in the future. He did not think any of the great groups of oil companies would hesitate to continue to prepare for the eventualities which they believed petroleum technologists would provide for them. They honestly believed that the technologists would provide the companies with all the oil that the world demanded, and that they could go along confidently preparing to receive it, making ready their refineries, their ships and their distributing organizations. If anyone was tempted in a moment of impatience to feel that there was no room for his neighbour he believed that moment would be a very short one. He believed that as time went on they would feel more and more the compelling necessity of co-operating together to improve the industry and to improve the service they rendered to mankind. The work of destruction to which all parts of the community were called during the last seven years had nearly come to an end, but no less effort would be demanded for the work of reconstruction, and he thought the petroleum technologists would undertake their part of the work that was demanded of them. Feeling, therefore, that the oil industry had a great future before it, that it had much to be thankful for in the technologists and a little to be thankful for in those who

carried on the next stage of the industry, it had been a great privilege for the guests to be invited to attend the dinner of the Institution, and he thanked the Council and the Members for the splendid evening that had been given to them.

During the dinner an excellent programme of music was rendered by the British Imperial Orchestra, under the direction of Mr. Arthur Crudge, and the speeches were interspersed with some much appreciated singing by Miss Lily Clare and Mr. George Webber.

CRYSTAL PALACE LECTURES ON PETROLEUM

The Council have arranged to publish in book form a complete series of the Crystal Palace Lectures, which will be rewritten and illustrated with some ninety-two diagrams and plates. The work is to be issued as a Popular Petroleum Book for the general petroleum-reading world, with glossary, statistical tables (including various weights and measures for technical reference), a bibliography and other useful information. The Council are anxious that the members should support this venture, and those members desiring to subscribe to the volume can obtain further information on application to the Secretary.

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